

September 2019

# Exploring Current Topics and Trends in Anatomy Education: A Scoping Review

Alex Wolf

*The University of Western Ontario*

Supervisor

Belliveau, Daniel

*The University of Western Ontario*

Graduate Program in Health and Rehabilitation Sciences

A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

© Alex Wolf 2019

Follow this and additional works at: <https://ir.lib.uwo.ca/etd>



Part of the [Anatomy Commons](#)

---

## Recommended Citation

Wolf, Alex, "Exploring Current Topics and Trends in Anatomy Education: A Scoping Review" (2019). *Electronic Thesis and Dissertation Repository*. 6501.

<https://ir.lib.uwo.ca/etd/6501>

This Dissertation/Thesis is brought to you for free and open access by Scholarship@Western. It has been accepted for inclusion in Electronic Thesis and Dissertation Repository by an authorized administrator of Scholarship@Western. For more information, please contact [wlsadmin@uwo.ca](mailto:wlsadmin@uwo.ca).

## **Abstract**

Within the field of health professional education, one finds that anatomy often presents students with a great deal of difficulty. The literature in this area is piecemeal and there is limited work available examining the whole of this topic. A scoping review was conducted to determine how students are taught anatomy across multiple disciplines (medicine, dentistry, rehabilitation sciences, and undergraduate education) and to assess for any notable differences between these populations. The results found that scholarship on anatomy instruction varies based on educational context, and medical students are the most frequently targeted student population. It also found that the use of medical imaging and computer aided instruction is increasing while the use of cadaveric dissection has remained constant. Furthermore, the lack of cadaveric dissection in an anatomy curriculum does not necessarily hinder student learning when alternative teaching modalities are implemented.

## **Lay Summary**

Anatomy is a complicated subject for students to learn, but it is critical in the delivery of safe clinical care by healthcare practitioners. Due to the complexity of anatomy, many healthcare professionals do not receive sufficient anatomy training. This thesis used a scoping review to capture how anatomy is taught to different student populations to assess the methods with which students are taught anatomy. It is expected that understanding this aspect of student education in the subject of anatomy will help lead to better educational outcomes.

## **Keywords**

Anatomy, education, teaching, learning, undergraduate, graduate, medical, dentistry, nursing, physiotherapy, physical therapy, occupational therapy, cadaveric dissection, prosection, medical imaging, computer-aided instruction, plastination, living anatomy, lecture-based learning

# Table of Contents

Abstract	i
Lay Summary	i
Keywords	i
Table of Contents	ii
List of Tables	iv
List of Figures	v
List of Abbreviations	vi
Acknowledgements	vii
Introduction	1
Background	2
Why Anatomy Education is Important	6
The Changing Environment: Shifts in Anatomy Education	8
Considering the Current State of Anatomy Education	10
Objectives	12
Methods	13
Identifying the Research Question	13
Identifying the Relevant Studies	14
Study Selection	15
Charting the Data	16
Collating, Summarizing, and Reporting Results	16
Results	18
Demographic Features	18
Distribution of Studies by Body Regions and Systems	18
Distribution of Studies by Student Population	19

Distribution of Studies by Category	20
Discussion	43
Cadaveric Dissection	45
Prosections	47
Plastination	47
Computer-Aided Instruction	48
Medical Imaging	52
Living Anatomy	54
Lecture-Based Learning	55
Integrated Curricula	55
System-Based Curricula	55
Alternative Teaching Methods	56
Exploring the Exclusion Criteria	62
Novel Classification of Tools for Anatomy Education	64
Moving Forward in Anatomy Education: What is Best?	68
Limitations	70
Future Directions	71
Conclusion	73
References	75
Appendix: Supplemental References	105
Curriculum Vitae	128

## List of Tables

Table 1. Student Population, Classification, Tool Used, and Targeted Body Region	24
Table 2. Cross Referencing Educational Tools by Student Population	41
Table 3. Classification and Grouping of Anatomy Learning Tools	65

# List of Figures

Figure 1: Outlining the Article Selection Process.	17
Figure 2: Distribution of Rejection Criteria	34
Figure 3: Proportion of Student Population	35
Figure 4: Total Number of Sources by Year	36
Figure 5: Trends Across Educational Interventions by Year	37
Figure 6: Total Number of Sources by Country	38
Figure 7: Body Regions Targeted in Literature	39
Figure 8: Body Systems Targeted in Literature	40
Figure 9: Percentage of Category	42
Figure 10: Percentage of Categories (Novel Classification)	67

## **List of Abbreviations**

AR: Augmented Reality

CAI: Computer Aided Instruction

CBL: Case-Based Learning

CT: Computed Tomography

IBL: Inquiry-Based Learning

MRI: Magnetic Resonance Imaging

PBL: Problem-Based Learning

SDL: Self-Directed Learning

TBL: Team-Based Learning

VR: Virtual Reality

3Dp: Three Dimensional Printed (model)

## Acknowledgements

First and foremost, I would like to thank my supervisor, Dan Belliveau. Words cannot express my gratitude for having such an amazing mentor throughout my both my undergraduate and masters degrees. Thank you for being patient with me and with all the challenges we experienced throughout. The lessons I have learned from you during this masters I will keep with me throughout the remainder of my education and professional career. Your guidance and wisdom will serve as a model for me for many years to come.

I would like to thank my family for their unwavering support and patience. This thesis would not have been possible without all of you. I would like to thank my mother in particular, for keeping me focused when things got tough and for cheering me on whenever I achieved another milestone.

Finally, to my friends and colleagues, I am so grateful to have had you by my side throughout. I can't be a student with you all forever, but the memories will last a lifetime.

alex wolf



## Introduction

Since its origins, anatomy has had a rich and fascinating history. It has been a cornerstone of medical education for hundreds of years and has stood the pedagogical test of time (Turney, 2007). For many centuries, cadaveric dissection was the basis of both anatomy education and medical education in general (Azer & Eizenberg, 2007; Vázquez et al., 2007).

Anatomy education is a discipline that has been shaped by its history (Finn & McLachlan, 2010). Many great minds have pondered the inner workings of the human body. Da Vinci produced many anatomical drawings, still prized today for their accuracy and intricate drawing technique (Bell & Evans, 2014). Galen's anatomical descriptions ruled the medical world for over 1500 years after his death. Herophilus was the first anatomist to be authorized to dissect a human body, and did so around 600 times (Calkins, Franciosi, & Kolesari, 1999). Vesalius, the father of modern anatomy, provided anatomic illustrations of surpassing quality rooted in meticulous dissection (Calkins et al., 1999). What these minds share in common is that their exploration of human anatomy was grounded in human dissection. The use of dissection was essential for accurately depicting the internal structure of the human body (Calkins et al., 1999).

Anatomy education has had the longest history of any component of medical education, and cadaveric dissection has been the predominant paradigm of anatomy education since the Renaissance (McLachlan & Patten, 2006). Many academics strongly support the use of cadaveric dissection as an integral part of anatomy education (e.g., Ahmad, Sleiman, Thomas, Kashani, & Ditmyer, 2016; Ramsey-Stewart, Burgess, & Hill, 2010).

As time has progressed, so too has anatomy and how it is taught. Cadavers are used less and less in educational settings; the halcyon days of hundreds of hours spent on anatomy instruction, dissection, and exploration have given way to the urgent and fast-paced environment of educating today's health care professionals.

## **Background**

This paper will provide a background into different approaches to teaching anatomy at different levels of post-secondary education to different student populations. Then, the paper will address whether or not there are clear differences in teaching curriculum or student expectations between different student populations taking anatomy courses.

## **Educational Context**

For this review, several student populations were considered, including:

1. Medical students
2. Dentistry students
3. Nursing students
4. Rehabilitation sciences students, including:
  1. Physiotherapist students,
  2. Occupational and physical therapy students
5. Undergraduate students

Physiotherapy, occupational therapy, and physical therapy students are considered one student population due to their similar training and career paths. Undergraduate students are unique from the rest of the student population because their degree type is not expected to lead them to a patient-focused career immediately after receiving their diploma. However, because these students may still take anatomy courses throughout their undergraduate degrees, they are an important population to take into consideration.

In general, these student populations vary in one key regard: whether the degree they are pursuing will lead them to patient-centred careers immediately after graduation. In North America, medicine, dentistry, and rehabilitation sciences programs require an undergraduate degree before students may pursue these studies. Compressed timeframe nursing programs may require an undergraduate degree before students can enrol. There are, however, exceptions to this. In Europe, students wishing to pursue these degrees may do so directly from their high school

studies, or after completing an undergraduate degree. Nursing will also lead to patient-centred careers immediately after graduation but do not require undergraduate degrees before the commencement of studies. What remains constant in each of these professions is that practitioners require a sound understanding of anatomy in order to successfully and safely care for their patients.

Conversely, anatomy can be taught at the undergraduate level in numerous different degree programs (such as biology, health sciences, kinesiology, medical sciences, pathology, and so on), but the anatomy encountered in these degrees does not immediately translate into the clinical or healthcare setting. In the case of undergraduate students, anatomy may be a required course for the program or an elective a student opts to undertake. This makes the undergraduate population unique, because the anatomy students learn might not directly relate to the career they pursue. However, the anatomy which students encounter during their undergraduate degrees may serve them later while pursuing other degrees and programs in health professions.

### **Teaching Modalities**

Estai & Bunt (2016) have recognized and explored the common tools used to teach anatomy to students. This paper was selected as a framework for this scoping review for its inclusion of a variety of teaching methods. The use of an existing scholarly paper as a foundation adds more rigour to the findings of this scoping review. In their paper, they identify nine major categories of teaching tools to aid medical students in learning anatomy:

- 1) **Cadaveric dissection:** the primary tool used to teach anatomy over the last 400 years, considered by some to be indispensable to learning anatomy (Netterstrøm & Kayser, 2008, as cited in Estai & Bunt, 2016). Not only does it aid in understanding and learning anatomy, it also contributes to medical professionalism and first encounters with death. However, this method is costly and time-consuming (Aziz et al., 2002, as cited in Estai & Bunt, 2016). Therefore, it has been suggested that dissection is only necessary for students that will

- become surgeons (Leung, Lu, Huang, & Hsieh, 2006, as cited in Estai & Bunt, 2016).
- 2) **Prosections:** dissections prepared for students by professional anatomists, reducing the number of cadavers needed to teach the same number of students. Prosections are better matched to system-based courses, rather than dissections that are conducive to anatomy taught by region (Leung et al., 2006, as cited in Estai & Bunt, 2016). Furthermore, they address some of the drawbacks of dissection, such as costs and time, and require fewer cadavers per student (Dinsmore, Paul, & Sweet, 1993; Nnodim, 1990; Pather, 2015, as cited in Estai & Bunt, 2016). However, they are dependent on the skill of the professional generating the prosections.
  - 3) **Plastination:** a method of preserving prosections, offering cost-effectiveness through increased longevity. Despite these advantages, they do experience shrinkage, loss of finer details, and loss of texture. Like prosected and dissected material, they need to be renewed; but still offer cost effectiveness through longer usage times and cheaper storage methods (Latorre et al., 2007, as cited in Estai & Bunt, 2016).
  - 4) **Computer-aided instruction:** enabled by recent advances in technology, computer aided instruction (CAI) resources have been implemented in response to reductions in teaching time and budgets, increased class sizes, and increased costs of cadaver labs. Studies examining their efficacy suggest that there is no clear proof that CAI alone is a superior approach than more traditional methods (Khot, Quinlan, Norman, & Wainman, 2013; McNulty, Halama, & Espiritu, 2004, as cited in Estai & Bunt, 2016), and are best used as a supplement to enhance learning rather than replacing traditional teaching methods (Durosaro, Lachman, & Pawlina, 2008, as cited in Estai & Bunt, 2016; Tam et al., 2010). A big domain within this category is the use of 3D representations of anatomy and virtual reality.
  - 5) **Medical imaging:** considered a valuable addition to dissection courses. Medical imaging provides *in vivo* visualization of anatomy (Gunderman & Wilson, 2005, as cited in Estai & Bunt, 2016). Incorporating medical imaging into anatomy education may promote better understanding of spatial relationships (Pabst,

- Westermann, & Lippert, 1986; Reeves, Aschenbrenner, Wordinger, Roque, & Sheedlo, 2004, as cited in Estai & Bunt, 2016). However, like CAI resources, it functions poorly as a standalone teaching modality (Aziz et al., 2002; Howe, Champion, Searle, & Smith, 2004, as cited in Estai & Bunt, 2016) and might be better used as an adjunct to other teaching methods. Furthermore, medical imaging cannot replace conventional dissection (Aziz et al., 2002; Gunderman & Wilson, 2005; Howe et al., 2004, as cited in Estai & Bunt, 2016).
- 6) **Living anatomy:** offers students the ability to safely practice clinical skills and is also considered more cost effective. Living anatomy often takes the form of peer physical examinations, ultrasonography, and body painting. This method is considered more cost effective than the use of real patients or model patients (Wearn & Bhoopatkar, 2006, as cited in Estai & Bunt, 2016). Body painting involves drawing anatomical structures on the body's surface, which is an active and tactile learning modality (Op Den Akker, Bohnen, Oudegeest, & Hillen, 2002, as cited in Estai & Bunt, 2016). Ultrasonography, however, is not widely taught in medical school (Brown, Adhikari, Marx, Lander, & Todd, 2012a).
  - 7) **Lecture-based teaching:** while lectures have remained a key part of anatomy education alongside dissection over the previous four centuries (Vázquez et al., 2007), it is criticized as outdated and ineffective. An alternative to this method is blended learning, which involves the integration of face-to-face teaching and online instruction (Graham, 2006, as cited in Estai & Bunt, 2016).
  - 8) **Integrated curricula:** specific areas of anatomical knowledge can be prioritized according to the needs of the student; minimal anatomy is taught to students working towards general practice and students working towards surgery or other specialized areas can receive advanced training later in their education. With this approach, core anatomical knowledge can be gained at the most appropriate level (Evans & Watt, 2005, as cited in Estai & Bunt, 2016).
  - 9) **System-based curricula:** learners can master one system of the body throughout all the body's regions before moving on to the next system, which has been found to be easier than learning the body by regions (Brooks, Woodley, Jackson, & Hoesley, 2015), and improve long term retention of the material (Arslan, 2014, as cited in Estai & Bunt, 2016).

The categories described by Estai and Bunt (2016) will serve as a guiding framework for this scoping review. While the nature of the Estai and Bunt paper is similar to this paper, there are some critical differences that distinguish the documents. First, the article focuses exclusively on students undertaking medical degrees, while the student populations included in this paper expands beyond undergraduate medical education. Second, the work of Estai and Bunt (2016) focuses solely on teaching modalities and strategies for medical students, rather than teaching strategies employed for a wider range of student populations. Finally, the work of Estai and Bunt (2016) can be considered a traditional literature review. The current paper undertakes a rigorous and formalized scoping review approach which will compliment and expand upon the work of Estai and Bunt (2016). The purpose of this paper is to capture the different approaches to teaching anatomy across multiple student populations and to identify many of the tools educators use to teach their students as possible.

## **Why Anatomy Education is Important**

For the medical student, anatomy is considered one of the cornerstones of medical curricula (Brooks et al., 2015; Topping, 2014), and the foundation of clinical skills (Ahmed et al., 2010; Cuddy, Swanson, Drake, & Pawlina, 2013; Estai & Bunt, 2016; Kerby, Shukur, & Shalhoub, 2011). Anatomy learning is seen as an essential component of medical training (Ma et al., 2016) and to medical practice itself (McLachlan, Bligh, Bradley, & Searle, 2004). Competent physicians and surgeons require a deep and complete understanding of anatomy for safe clinical practice (Estai & Bunt, 2016). Anatomy is the basis of modern medicine (Chen et al., 2017).

While anatomy is particularly relevant to the field of surgery, it remains relevant to all health care specialties (Ma et al., 2016; Sugand, Abrahams, & Khurana, 2010). Nurses, physiotherapists, physical therapists, occupational therapists, audiologists, speech language pathologists, and dentists all require a deep understanding of anatomy for their practice, even if their knowledge of anatomy is limited to a certain region or system of the body. While these professionals might specialize in a

particular region or system of anatomy, it is still important for that professional to be well versed in that anatomy for safe and successful practice. As is the case for medical students, anatomy serves as a basis for their clinical skills. Visualizing the structure of the human body is critical for building a strong clinical knowledge base (Carter, Patel, Hocum, & Benninger, 2017).

The outcome of professional patient care has been found to be based on the level of anatomy knowledge of the health care professional (Smith & Mathias, 2010). Too often, students learn anatomy to pass examinations while forgetting details afterwards (Smith & Mathias, 2010), which does not establish a positive and sound understanding of anatomy for safe clinical practice. All health care professionals will be required to apply their anatomical knowledge in diagnostic or therapeutic contexts throughout their career (Sweeney, Hayes, & Chiavaroli, 2014). The changes in medical curriculum, in particular, reflect this, as the preoccupation with technical knowledge has transitioned into attitudes and skills for patient care (Dinsmore et al., 1993). Moreover, anatomy is an essential communication tool for healthcare professionals, as it is a common platform of knowledge suitable to all healthcare careers (Turney, 2007). Therefore, anatomy also takes on a professional aspect.

The link between anatomy and clinical skills is an important one. Anatomy knowledge serves as a foundation upon which clinical knowledge and skills can be built (Cuddy et al., 2013). Learning and developing clinical skills depends on understanding relevant and interrelated surface anatomy, clinical anatomy, and radiological anatomy (Dangerfield, Bradley, & Gibbs, 2000). Anatomy knowledge permits the safe execution of skills in the clinical setting and results in better outcomes for patients.

However, the reduction of anatomy in curricula compromises the opportunity for students to learn and safely practice clinical skills, and compromises patient outcomes. In the last three decades, there has been a downward trend in the amount of hours devoted to anatomy education (Craig, Tait, Boers, & McAndrew, 2010; Drake, McBride, Lachman, & Pawlina, 2009; Shaffer, 2004; Sritharan, 2005).

Over approximately five decades, time given to anatomy and dissection in US medical schools has declined by 50% with an 11% reduction on average between 2002 and 2009 (Drake et al., 2009). There is also a great deal of variability in the number of hours dedicated to anatomy in anatomy courses in higher level education within the same country. For example, this is seen in Ireland (Heylings, 2002), as well as Australia and New Zealand (Craig et al., 2010). The variability between institutions in these countries, as well as the global differences in level of anatomy instruction, implies that the time dedicated to anatomy education is insufficient or incompatible with safe clinical practice. If one institution believes the level of anatomy being taught to students is sufficient yet it differs from a second institution, it must be concluded that at least one institution (if not both) must therefore be incorrect about their assumptions as to what constitutes an appropriate level of anatomy instruction.

## **The Changing Environment: Shifts in Anatomy Education**

As demonstrated (e.g., Cuddy et al., 2013; Smith & Mathias, 2010; Sweeney et al., 2014), the link between anatomy and safe clinical practice among health care practitioners is highly supported throughout the literature. A reduction in the quality and quantity of anatomy teaching results in deleterious outcomes for professional practice across many domains of healthcare.

This reduction of teaching hours and resources dedicated to anatomy instruction has caused worry among healthcare professionals, educators, and students alike. Some professionals have suggested that the level of anatomy education has fallen below a safe level (Fitzgerald, White, Tang, Maxwell-Armstrong, & James, 2008; Turney, 2007). Many practitioners feel that medical students' knowledge of anatomy is inadequate (Dusseau, Knutson, & Way, 2008). Curricular time for gross anatomy is often an area of concern for anatomy instructors (Brooks et al., 2015); instructors find themselves teaching an "overview" of the human body rather than allowing students to explore and investigate the human body (Gillingwater, 2008). Students themselves have also reported that they feel their level of anatomy education is insufficient (Fitzgerald et al., 2008; Mitchell & Batty, 2009; Watmough, O'Sullivan, &



Taylor, 2010) and requires more structure and time dedicated for safe clinical practice (Ahmed et al., 2010).

It is not surprising that changes in anatomy curricula have degraded intended learning outcomes expected from anatomy education (Ahmed et al., 2010). The misunderstanding that anatomy is content-driven, rather than skills based, may be to blame for the reduction of teaching hours dedicated to anatomy (Patel & Moxham, 2006), especially in medical contexts. Other reasons for curricular change include increasing subject matter integration and the increased use of electronic and technological resources (Drake et al., 2009). Finally, anatomy is no longer seen as a research-led discipline (McLachlan & Patten, 2006; Yammine, 2014), furthering the decline of hours and interest dedicated to anatomy.

Anatomy education has undergone many changes in its curriculum, teaching modalities and resources, and assessment methods (Hadie et al., 2017). The advancement of technologies and electronic devices necessitates changes in academic methodologies (Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015). To improve anatomy education, changes and innovations in teaching and assessment are required (Bergman et al., 2013). However, when designing curricula, instructors are often prone to focusing on teaching methods over learning outcomes, even though learning outcomes should take priority (Patel & Moxham, 2008).

A tangible outcome of the recent changes is increased litigation for medical malpractice. "Anatomical ignorance" has led to more malpractice suits brought against doctors (Waterston & Stewart, 2005). However, it remains difficult to determine what level of anatomy education is safe for clinical practice (Craig et al., 2010; Waterston & Stewart, 2005). This is an important aspect to consider. Universities cannot afford to produce negligent medical graduates whose careers often last about 40 years (Sugand et al., 2010). Likewise, other healthcare workers who have long careers working with patients need to be able to safely practice their

profession, and one of the pillars of safe practice is a sound understanding of anatomy.

Traditional methods of learning anatomy purely from cadavers, textbooks, and lectures are becoming obsolete and historical (Finn, White, & Abdelbagi, 2011). Medical schools have been moving away from cadaveric dissection, instead employing the use of prosections, living anatomy, and plastic models (Griksaitis, Sawdon, & Finn, 2012). The traditional teaching methods are criticized for being teacher centred and for treating students as passive participants (Kolossvary, Szekeley, Gerber, Merkely, & Maurovich-Horvat, 2017). Anatomy education often makes the mistake of assuming students form a homogenous group (Lufler, Zumwalt, Romney, & Hoagland, 2010). This assumption leaves students at a disadvantage, as learners inevitably fall through the cracks of an education system that is failing them.

Despite the criticism aimed at anatomy education, there is a great deal of positivity centred around new teaching methods. The quality of current curricula can be improved through implementing novel teaching methods and tools (Ahmed et al., 2010). The exponential increase in technology and its adoption in society provides exciting new learning tools, and new understandings of more traditional teaching methods.

## **Considering the Current State of Anatomy Education**

Anatomy instruction is at a crossroads (Shaffer, 2004). Traditional anatomists have questioned and challenged the advent of new teaching methods (Tam, Hart, Williams, Heylings, & Leinster, 2009), while proponents of these teaching methods often fail to see the value of traditional teaching modalities (Heylings, 2002). Despite rhetoric from both sides of this schism, there seems to be no clear answer to the question, "what is the best way to teach anatomy to students?" Some scholars answer that there is no single method that can function as an answer to this question (Bergman, 2015). No single teaching method has been proven to be superior to the rest (Johnson, Charchanti, & Troupis, 2012; Turney, 2007), and

perhaps no individual method ever will. The closest any single teaching modality has come to being superior to all others is cadaveric dissection, which is still regarded as the “gold standard” of anatomy education by scholars and doctors alike (Parker, 2002; Patel & Moxham, 2008).

It can be difficult for instructors to determine the best tools and strategies to employ due to the plethora of available choices (Vázquez et al., 2007). Some studies argue for the use of multiple teaching modalities in combination to encourage student learning (e.g., Estai & Bunt, 2016; Finn & McLachlan, 2010; Ivanusic, Cowie, & Barrington, 2010; e.g., Mitchell & Batty, 2009; Peeler, Bergen, & Bulow, 2018; Snelling, Sahai, & Ellis, 2003). Others argue that both traditional and technology-based approaches should be used together when teaching students (e.g., Codd & Choudhury, 2011; Elizondo-Omaña, Guzmán-López, & García-Rodríguez, 2005; Jarral, Mehboob, & Ashraf, 2017; Kugelmann et al., 2018; Stewart & Choudhury, 2015; Yeom, Choi-Lundberg, Fluck, & Sale, 2013). In both arguments, there is a commonality in the belief that multiple different teaching methods used together may facilitate learning. However, the question then becomes; “which teaching methods are best used in combination, and which teaching methods don’t work well with others?” There is no clear answer to this question either. And amidst all this debate among scholars, students still report a tendency to prefer traditional teaching methods over other learning resources (Choi-Lundberg, Cuellar, & Williams, 2016). To this point, McLachlan and Patten (2006) still argue that dissection should remain a key aspect of anatomy education to prepare health professional students for future clinic work.

The best way to teach anatomy continues to be debated among scholars (Elizondo-Omaña et al., 2005; Estai & Bunt, 2016; Tam et al., 2009), and will likely continue to be debated for the foreseeable future. As the debate continues, medical professionals are sent into the healthcare system lacking a proper level of anatomy training, and this puts patients at risk for harm, and professionals at risk for litigation. This may not be a concern for undergraduate students who are not directly entering into the healthcare system, but they are still an important student

population to consider because the anatomy they learn in their undergraduate degrees may become the foundation for the anatomy they learn while preparing for their patient-centred careers. After all, the things one learns first are the most influential (Miller, 2000).

## **Objectives**

The purpose of this study is to examine the various teaching methods used across differing student populations. In particular, the study asks the following questions:

- 1) How does the existing literature on anatomy education describe the various approaches to teaching anatomy to different student populations engaged in clinical or non-clinical degree programs?
- 2) Are there clear differences in how different student populations are taught anatomy?

A scoping review is employed to gather literature and research studies pertaining to the research question; whether or not there are differences in anatomy education across student populations. This study includes a breadth of student populations to provide a wholistic understanding of trends and themes related to teaching anatomy. It is expected that the unique student populations would capture a wide variety of teaching methods.

## Methods

The approach taken for this scoping review followed the recommended stages set out by Arksey & O'Malley (2005), with additional recommendations taken from Grant & Booth (2009). Arksey & O'Malley (2005) set out a methodological framework that is based on 5 stages:

- **Stage 1:** identifying the research question
- **Stage 2:** identifying the relevant studies
- **Stage 3:** study selection
- **Stage 4:** charting the data
- **Stage 5:** collating, summarizing, and reporting the results

There are four reasons to conduct a scoping review: (1) to examine the extent and nature of research activity, (2) to determine the value of undertaking a systematic review, (3) to summarize and disseminate research findings, and (4) to identify research gaps (Arksey & O'Malley, 2005). This paper intends to explore the field of anatomy education and determine if there is consensus in the literature as to whether there are significant differences in educating various student populations. Additionally, this paper will determine if there is a sufficiently large gap in the literature that researchers should endeavour to bridge with additional study.

Grant & Booth (2009) state that a scoping review provides a preliminary assessment of the size and scope of available research literature. This type of review typically characterizes the quality and quantity of literature (Grant & Booth, 2009). By examining all types of anatomy education across multiple domains of student education, it is expected that this scoping review will accurately assess the quality and quantity of the literature surrounding the instruction of anatomy.

### Identifying the Research Question

This scoping review sets out to establish if there are clear differences in the anatomy curriculum for students studying in various educational contexts, and if so, what those differences are. The literature on anatomy education is often based on

anecdotal evidence rather than rigorous research findings (Craig et al., 2010; Vorstenbosch, Bolhuis, van Kuppeveld, Kooloos, & Laan, 2011). This scoping review aims to objectively examine the literature to obtain an unbiased understanding of current trends and topics in anatomy education, and to determine which methods are available and commonly used by instructors and professors.

There are many studies in the literature regarding educational interventions for anatomy courses. Some articles focus on the current state of anatomy education, some examine different tools and features of effective anatomy education, and others discuss levels of anatomy education required in different domains of clinical practice. There is an absence of literature examining which interventions are best suited for different student populations. In this case, a scoping review is most appropriate, as this research question has not been thoroughly explored in previous research efforts and could serve as a guide to future efforts in the area.

The scope of this paper is limited by several inclusion and exclusion criteria, and is not restricted by the learning tools implemented in the included research. Therefore, a wide variety of teaching methods were included, and should therefore capture the essence of anatomy education from the previous decade.

## **Identifying the Relevant Studies**

PubMed, Scopus, and ERIC were all searched using the search phrase “anatomy AND education AND learning,” using titles, abstracts, and keywords to capture relevant articles. These databases were searched up to the 30th April 2019, and the search was limited to a ten year period. This was selected due to the rapid development of educational technology. By limiting the research results to the last ten years, the studies that used technology in their research design would be more refined and mature, and therefore be better suited to compare to other modalities of teaching. It is expected that this will offer a more fair, objective comparison between different learning tools implemented in the anatomy classroom.

The databases were searched because they were believed to contain the most number of relevant articles that could be included in the scoping review. PubMed and Scopus both are primary repositories of articles from the medical community, and ERIC provides articles that focus on educational interventions.

## **Study Selection**

All studies captured from database searching were passed through two levels of review. In the first phase of review, articles were first assessed for relevance to the research question, and the titles and abstracts were assessed by the inclusion and exclusion criteria. Arksey & O'Malley (2005) emphasize that this is not a linear process, as early findings can be reshaped by new insights. As such, the criteria were developed *ad-hoc* throughout the first phase. As the body of literature became more familiar, more relevant and specific criteria could be developed. The article selection and analysis was conducted by one reviewer.

During the second phase of review, articles were examined by their full text. They were judged for inclusion or rejection by applying the same criteria. At this point, the inclusion and exclusion criteria had been finalized from the first phase of review. This ensured consistency in the final selection of articles for the scoping review.

An article was included if it:

- 1) Discussed anatomy curricula in a classroom setting for the study of medicine, dentistry, rehabilitation sciences, or students in their undergraduate degree. A paper would be considered if it examined grade impacts created by the intervention or curriculum change, or gathered student perceptions on an intervention or curriculum change.
- 2) Had an educational intervention clearly aimed at the targeted student populations.
- 3) Discussed anatomy curriculum in the context of educational interventions.

An article was excluded on the following criteria:

- 1) The paper did not include sufficient detail on the curricula or educational intervention being implemented, or targeted clinical rather than educational or classroom settings.
- 2) The paper did not clearly target a clinical or non-clinical student population delineated in the introduction.
- 3) The paper focused on the creation, maintenance, or professional-based assessment of a learning tool or testing method, rather than the implementation or impact on student learning outcomes. Reviews and editorials were also eliminated in this criterion, as were discussions of curricular change. Papers that gathered survey responses and opinions from institution members or recent graduates were not included.
- 4) The papers included an examination of related courses (including physiology, histology, pathohistology, embryology, pathology, genetics, neuroanatomy and neuroscience, biology, biomechanics, etc.).

Furthermore, the search results were limited to a ten year period.

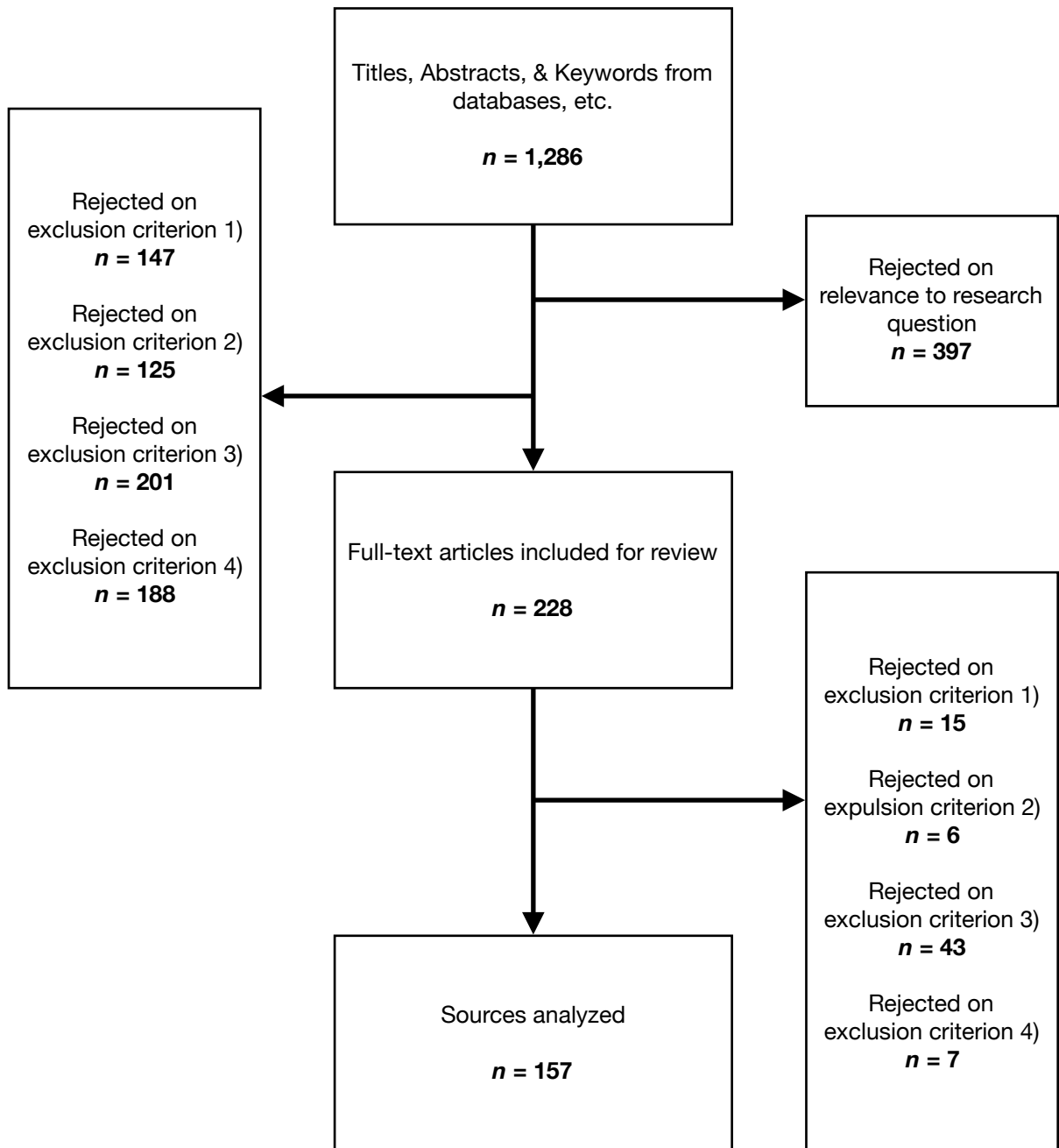
## **Charting the Data**

The articles included for review were listed and organized in a table including author names, the article name, and year of publication, and country. A second table tracked the student population targeted by the authors of the paper, the classification of the learning tool according to the categories put forth by Estai and Bunt (2016), the tool or educational intervention used by the study, and the specific body system or region the tool targeted (where applicable). The entry numbers are consistent between each table for reference.

## **Collating, Summarizing, and Reporting Results**

All sources included for review were sorted and stored in EndNote (version 9.1.1, Clarivate Analytics, Philadelphia). After all databases were searched, duplicates removed, and inclusion and exclusion criteria applied, the final papers selected for analysis were subjected to a qualitative analysis of the key findings.





**Figure 1: Outlining the Article Selection Process.**

Articles went through several rounds of review. The first assessed for relevance, and articles that were not relevant to the research question were removed. In the second round, articles were judged on both their titles and abstracts. Articles that remained after this round were subject to a full text analysis, and which point the final articles were removed before the remainder were charted for the scoping review. Where an article was rejected on multiple exclusion criteria, it was only counted against the single most relevant criterion.

## Results

In total, 157 papers were included for analysis. The authors, title, year, and country of the articles included in the scoping review can be found in Table 1. Information about the student population, intervention used, and body region or system focused on can be found in Table 2.

PubMed returned 710 results, Scopus yielded 594, and ERIC provided 439 papers. In total, 1,743 papers were captured, and after 457 duplicates were accounted for and removed, there were 1,286 papers (Figure 1). This first phase of review had 397 papers removed on the basis of relevance. Another 732 papers were removed pursuant to the four rejection criteria (Figure 2). This left 157 papers for analysis.

## Demographic Features

Papers were published from all areas of the world, with a large concentration from the United States ( $n = 46$ ), Australia ( $n = 21$ ), the United Kingdom ( $n = 17$ ), and Canada ( $n = 10$ ), representing approximately 60% of the total literature included in this review (Figure 6). Beyond this, the publication origin was widely varied, with over half of the countries having only a single article included for review and 80% having 3 or fewer articles. In general, the number of publications that were captured by the search criteria increased year over year (Figure 4).

## Distribution of Studies by Body Regions and Systems

More studies examined the body by region ( $n = 80$ ) (Figure 7) than by system ( $n = 12$ ) (Figure 8). If a researcher clearly identified a region or system in their study, it was recorded in Table 2 and in Figures 7 and 8. However, if a researcher declared which type of anatomy curricula was employed in their focus group, it was not necessarily considered among the Systems-Based Curricula category offered by Estai and Bunt (2016).

Some teaching methods (such as cadaveric dissection) were more suited to a regional approach to teaching, others (such as computer models and graphics)

were well suited to a systems-based approach. There were also methods that showed no specificity to either regional or systems-based teaching, such as problem based learning and peer teaching.

## **Distribution of Studies by Student Population**

### **Medical Students**

Medical students were the most frequently targeted student population, representing 72% of the literature (Figure 3). Medical imaging was the most common category explored with medical students (32%), followed by CAI (18%) and cadaveric dissection (16%). Plastination (1.3%) and prosection (3.2%) were the least explored categories among interventions for medical students. An additional 25% of the teaching strategies and modalities used for medical students did not fit the categories offered by Estai and Bunt (2016).

### **Dentistry Students**

Dentistry students were included in 6% of the literature (Figure 3). This smaller percentage may be explained by the fact that the anatomy they need to know is limited to a small region of the body. Cadaveric dissection and CAI each represented 23% of the educational interventions used among dental students. Medical imaging (n = 2), plastination (n = 1) and living anatomy (n = 1) were also used in this student population. An additional 23% of the interventions used for dental students did not fit into the categories offered by Estai and Bunt (2016).

### **Nursing Students**

Nursing students represented the smallest percent of the literature (4%) (Figure 3). The low percentage of nursing students captured in this scoping review may suggest that anatomy is not viewed as an important component of nursing training. Within the literature focusing on nursing students, 50% did not conform to the categories of Estai and Bunt (2016).

### **Rehabilitation Sciences Students**

Studies with rehabilitation sciences students appeared 7% of the time in the literature, marginally ahead of the number of dentistry-focused studies (Figure 3). Approximately 67% of the literature focused on this population explored the use of CAI. Cadaveric dissection and prosections were also explored in this population, each accounting for approximately 17%.

### **Undergraduate Students**

Only 11% of the included literature was focused on non-professional program, undergraduate students (Figure 3). The remaining 89% of the literature targeted students in healthcare oriented degrees. The majority of the educational interventions targeted at this population were computer-aided learning methods (71%). This is likely due to the ability to implement computer-based resources in large classes in a cost-effective manner. Another two studies examined the use of medical imaging among this student population. Living anatomy and cadaveric dissection each appeared once as an intervention for undergraduate students.

## **Distribution of Studies by Category**

### **Cadaveric Dissection**

Overall, 29 papers (13%) focused on cadaveric dissection as a discrete learning tool ( $n = 8$ ), or in combination with other educational interventions ( $n = 21$ ) (Figure 9). Cadaveric dissection has long been regarded as a key component of medical education, most studies around cadavers have focused on medical students (Mc Garvey, Hickey, & Conroy, 2015). This was true in this scoping review: 77% of the articles that used cadaveric dissection focused on medical students. Nursing and undergraduates were the least targeted student groups for cadaveric dissection, with only 3% of the literature each. The combination of all categories using cadaveric specimens (dissection, prosection, and plastination) represented almost 60% of all literature included in the scoping review. This indicates that the use of cadaveric material is still effective and important, even as teaching methods continue to develop and evolve. Across the ten year period examined by this

scoping review, the rate of publication focused on cadaveric dissection remained fairly constant, except for one spike in the number of publications in 2016 (Figure 5).

### **Prosections**

Eight papers (4%) examined the educational impact of prosections on student learning and comprehension (Figure 9). Prosection never appeared in isolation as its own learning tool, and was always accompanied by another intervention. These included cadaveric dissection, plastination, computer-based resources, and medical imaging. Medical students were the most common student population to be targeted by prosections (63%), even though prosections and plastination each were the least common form of intervention for medical students. Like cadaveric dissection, the number of publications per year focusing on prosections was low, and never exceeded more than three papers each year (Figure 5).

### **Plastination**

Medical students again represented the most frequently targeted group (50%) for interventions that used plastination; nursing students and dentistry students represented the other half of the student populations targeted by plastination-based interventions. As an educational intervention, it appeared on its own half of the time, and was combined with another teaching strategy the remaining half of the time it appeared in the literature. There was no discernible pattern in the number of times per year a publication included it as an educational intervention (Figure 5).

### **Computer-Aided Learning**

Among the categories offered by Estai and Bunt (2016), computer-aided learning was second only to medical imaging and captured 21% of the literature obtained in the scoping process (Figure 9). Computer-aided learning took many forms, and was therefore the most versatile learning tool found in the literature. These included AR ( $n = 7$ ), VR ( $n = 4$ ), online learning and forum discussions ( $n = 10$ ), and the use of mobile devices ( $n = 2$ ). Computer-aided instruction was the most prevalent form of educational intervention for undergraduate students, and 75% of all educational interventions for medical students involved CAI. Computer-aided instruction saw a

steady increase in the amount of attention it received throughout the research period (Figure 5).

### **Medical Imaging**

Medical imaging constituted 24% of the included literature, making it the largest category (Figure 9). It took various forms, such as X-Ray (n = 6), Magnetic Resonance Imaging (MRI) (n = 4), and Computed Tomography (CT) (n = 15). Ultrasound was the most common form of medical imaging (n = 17, 40%). Along with CAI, the use of medical imaging increased across the ten year period of this scoping review (Figure 5).

### **Living Anatomy**

Living anatomy constituted only 3% of the overall literature captured (Figure 9), and showed no consistency when analyzed by the number of publications per year focusing on this modality (Figure 5). It was mainly implemented as body painting (50%) for medical students to help teach surface anatomy. The other half of the literature in this domain used ultrasonography on student peers to teach the relation between surface features and deeper anatomy. This subset of the literature is included in the Living Anatomy category for its use of real people (students), whereas other studies use medical imaging on cadaveric specimens.

### **Lecture-Based Learning**

Lecture-based learning was not widely explored in the literature. This may be due to its existing relationship with anatomy that has extended over the previous four centuries. Only a single paper addressed this category, exploring how to make lectures more interactive for medical students.

### **Integrated Curricula**

The literature that discussed integrated curricula was limited to only one paper. This was expected, since this category is only relevant to medical students and the nature of this topic mainly focuses on the structure of curricula, not necessarily the ways in which anatomy in particular is taught to students. Discussion of curricular

changes or structure with no clear educational intervention was excluded from the scoping review. Therefore, it may be underrepresented in this document, as it lay beyond the purview of the scoping review.

### **System-Based Curricula**

Although a mix of system-based and regional-based anatomy studies were encountered in the literature, the number of papers addressing this category were scarce. This is likely because of the nature of the research question and the inclusion and exclusion criteria.

### **Unassigned**

Interestingly, 33% of the papers included for review used learning tools that could not be captured by one of the categories laid out by Estai and Bunt (2016) (Figure 9). This provides the basis and justification for re-categorizing the types of anatomy instruction used to teach students, and will be explored further in the discussion section.

The most common uncategorized learning tools included problem-based learning (PBL) (n = 5), case-based learning (CBL) (n = 4), inquiry-based learning (IBL) (n = 2) and team-based learning (TBL) (n = 5). Furthermore, peer teaching (n = 5) and 3D printed (3Dp) models (n = 10) represented large areas of research literature that did not fit neatly into one of the categories.

**Table 1. Student Population, Classification, Tool Used, and Targeted Body Region**

Author(s)	Year	Country	Student Population	Classification	Tool Used	Specified Region / System
Abed Rabbo et al.	2016	France	Medicine	Cadaveric dissection Medical imaging	Cadaveric dissection Ultrasound	Knee Ankle
Abu Eid et al.	2013	United States	Dentistry		Tooth carving	Oral
Agius et al.	2018	United States	Medicine		Peer teaching	Leg Foot
Agius & Stabile	2018	Malta	Medicine		Peer assisted Learning	
Ahmad et al.	2016	United States	Dentistry	Computer-aided instruction Cadaveric dissection	Audiovisual supplement Cadaveric dissection	Head and neck
Al-Madi et al.	2018	Saudi Arabia	Dentistry		Problem-based learning	Head and neck
Alfalah et al.	2018	Jordan	Medicine	Computer - aided instruction	Virtual reality	Heart
Alsaid & Bertrand	2016	Syria	Medicine		Drawing	Head and neck - muscles of facial expression
Anand et al.	2018	India	Nursing Medicine		Comics	
Ang et al.	2018	Singapore	Medicine		Games	
Anstey	2017	Canada	Undergrad		Inquiry-based learning	
Anstey et al.	2014	Canada	Undergrad		Inquiry-based learning	
Arya et al.	2013	United States	Medicine	Medical imaging	Radiology 3D models	
Attardi et al.	2016	Canada	Undergrad	Computer - aided instruction	Online learning	
Aversi-Ferreira et al.	2010	Brazil	Medicine	Cadaveric dissection	Cadaveric dissection	
Backhouse et al.	2017	United Kingdom	Medicine		Drawing	
Baker et al.	2013	United States	Dentistry	Plastination	Plastination	



<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Baker et al.	2013	United States	Dentistry	Plastination	Plastination	
Bareither et al.	2013	United States	Undergrad		Clay modeling	
Barton et al.	2018	United States	Undergrad Occupational Therapy Physical Therapy	Cadaveric dissection	Cadaveric dissection Peer learning	
Battulga et al.	2012	Japan	Medicine	Computer - aided instruction	3D computer graphics	Shoulder
Bell & Evans	2014	United Kingdom	Medicine		Art, drawing	
Bergman et al.	2013	Netherlands	Medicine		Problem-based learning	
Berney et al.	2015	France	Undergrad		3D models	Shoulder
Bohl et al.	2011	United States	Medicine	Cadaveric dissection Medical imaging	Cadaveric dissection CT scans	
Bork et al.	2019	Germany	Medicine	Computer - aided instruction	Augmented reality	
Brown et al.	2012	United States	Medicine	Medical imaging	Ultrasound	Head and neck
Brown et al.	2012	United Kingdom	Medicine	Medical imaging	Stereoscopic imaging	Aorta
Bruno et al.	2016	Canada	Undergrad		Peer teaching	
Buenting et al.	2016	Germany	Medicine	Cadaveric dissection Medical imaging	Cadaveric dissection CT scans	
Burgess & Ramsey-Stewart	2015	Australia	Medicine	Cadaveric dissection	Cadaveric dissection	
Cai et al.	2018	Singapore	Medicine		3D printed model	Knee
Canty et al.	2015	Australia	Undergrad	Medical imaging	Ultrasound	Heart
Carter et al.	2016	Canada	Medicine	Medical imaging	Ultrasound	

Author(s)	Year	Country	Student Population	Classification	Tool Used	Specified Region / System
Carter et al.	2017	Canada	Medicine	Medical imaging Cadaveric dissection	Ultrasound Cadaveric dissection	Head and neck - thyroid
Chen et al.	2017	China	Medicine		3D printed model	Head and neck - skull
Chimmalgi	2019	India	Medicine	Cadaveric dissection	Interactive lecture Cadaveric dissection	
Choi-Lundberg et al.	2016	Australia	Medicine	Cadaveric dissection Computer-aided instruction	Cadaveric dissection Audio-visual materials	
Christensen et al.	2018	United States	Medicine		Peer teaching	
Codd & Choudhury	2011	United Kingdom	Undergrad	Computer-aided instruction	Virtual reality	Forearm
Cui et al.	2017	United States	Medicine	Medical imaging	Stereoscopic imaging	Head and neck
Dettmer et al.	2013	Germany	Medicine	Medical imaging	X-Rays CT scans	
Dickman et al.	2017	Israel	Medicine		Peer teaching	
Durán et al.	2012	Mexico	Medicine		Peer teaching	
Fergusson et al.	2018	Scotland	Medicine	Computer-aided instruction	Audience response system	
Ferrer-Torregrosa et al.	2015	Spain	Undergrad	Computer-aided instruction	Augmented reality	
Findlater et al.	2012	Scotland	Medicine		Self-directed learning	
Finn & McLachlan	2010	United Kingdom	Medicine	Living anatomy	Body painting	
Finn et al.	2011	United Kingdom	Medicine	Living anatomy	Body painting	
Fleagle et al.	2018	United States	Dentistry	Cadaveric dissection Computer-aided instruction	Cadaveric dissection 3D digital animations	
Fritz et al.	2011	Canada	Medicine Dentistry Physical Therapy	Computer-aided instruction	3D computer model	Head and neck - larynx

<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Ghorbani et al.	2014	Iran	Physical Therapy		Team based learning	Lower limb
Green et al.	2014	Australia	Physiotherapy	Computer-aided instruction	Online forum discussion	
Green & Hughes	2013	Australia	Undergrad Physiotherapy	Computer-aided instruction	Online forum discussion	
Green & Whitburn	2016	Australia	Physiotherapy	Computer-aided instruction	Online forum discussion	
Greene	2018	United States	Medicine	Computer-aided instruction	Drawing, screencasts	
Griksaitis et al.	2012	United Kingdom	Medicine	Medical imaging Prosection	Ultrasound Prosection	Heart
Hampton & Sung	2010	United States	Medicine	Computer-aided instruction	Computer trainer	Pelvic Floor (female)
Herrmann et al.	2015	Switzerland	Medicine Nursing		Inter-professional learning	
Hill & Nassrallah	2018	United States	Medicine		Games	Liver
Holland & Pawlikowska	2018	Ireland	Medicine		Case-based learning	GI tract and liver
Horneffer et al.	2016	Germany	Medicine Dentistry	Cadaveric dissection	Peer tutoring Cadaveric dissection	
Hoyek et al.	2014	France	Undergrad	Computer-aided instruction	3D digital animations	
Inuwa	2012	Oman	Medicine		Team based learning	
Ivanusic et al.	2010	Australia	Medicine Dentistry Undergrad	Medical imaging Living anatomy	Ultrasound Living anatomy	Heart
Jaffar	2012	United Arab Emirates	Medicine	Computer-aided instruction	Youtube videos Problem-based learning	
James et al.	2018	United Kingdom	Medicine	Plastination	Plastination	Foot and ankle
Janssen et al.	2015	Australia	Medicine		Games Team based learning	
Jariyapong et al.	2016	Thailand	Medicine	Living anatomy	Body painting	Hand

<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Jarral et al.	2017	Pakistan	Medicine		Case-based learning	Cardio-respiratory systems
Jurjus et al.	2014	United States	Medicine	Medical imaging Living anatomy	Ultrasound Living anatomy	
Keedy et al.	2011	United States	Medicine	Computer-aided instruction	3D computer model	Hepato-biliary system
Kelly et al.	2018	Australia	Physiotherapy	Computer-aided instruction	Augmented reality	
Kharb	2016	India	Medicine	Computer-aided instruction	Online learning	Pelvis (female)
Kinirons et al.	2018	United States	Physical Therapy Occupational Therapy	Cadaveric dissection Prosection	Cadaveric dissection Prosection Peer teaching	
Knobe et al.	2012	Germany	Medicine	Medical imaging	Ultrasound Arthroscopy	Shoulder Knee
Kolossvary et al.	2017	Hungary	Medicine	Prosection Medical imaging	Prosection CT scans	Heart
Kondrashova et al.	2017	United States	Dentistry	Medical imaging	Ultrasound	Maxillo-facial structures
Kong et al.	2016	China	Medicine	Computer-aided instruction	3D printed model 3D graphics	Hepato-biliary system
Kooloos et al.	2014	Netherlands	Medicine		Clay modeling	Musculo-skeletal system Nervous system
Kotzé et al.	2012	South Africa	Medicine	Cadaveric dissection Medical imaging	X-Rays Cadaveric dissection	Surface anatomy
Kugelmann et al.	2018	Germany	Medicine	Computer-aided instruction Medical imaging	Augmented reality Sectional imaging	
Lai et al.	2019	Taiwan	Nursing	Cadaveric dissection	Cadaveric dissection	

<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Larkin & McAndrew	2013	Australia	Medicine	Cadaveric dissection	Cadaveric dissection	
Lazarus et al.	2017	South Africa	Medicine	Computer-aided instruction	Mobile devices	
Lefroy et al.	2011	United Kingdom	Medicine		Pipe cleaners	Brachial plexus
Li, Z et al.	2015	China	Medicine	Medical imaging	CT scans 3D images 3D printed model	Spinal cord
Lim et al.	2016	Australia	Medicine	Cadaveric dissection	3D printed model Cadaveric dissection	Heart
Lufler et al.	2019	United States	Medicine		Peer teaching	
Lufler et al.	2010	United States	Medicine	Cadaveric dissection Medical Imaging	Cadaveric dissection CT scans	
Machado et al.	2013	Portugal	Medicine	Medical imaging	CT scans MRI scans	
Maresky et al.	2019	Canada	Medicine	Computer-aided instruction	Virtual reality	Heart
Marker et al.	2010	United States	Medicine	Medical imaging	Medical imaging resource centre	
Marker et al.	2012	United States	Medicine	Medical imaging	Medical imaging resource centre	
Marshak et al.	2015	United States	Medicine	Cadaveric dissection	Cadaveric dissection Peer teaching	
Marsland et al.	2018	Australia	Medicine	Medical imaging	X-Rays CT scans MRI scans	Pelvis
Marsland et al.	2018	Australia	Medicine	Medical imaging	X-Rays CT scans MRI scans	Abdomen
Martinez et al.	2014	Columbia	Medicine		Team based learning	Musculo-skeletal system
Mathiowetz et al.	2016	United States	Occupational Therapy	Computer-aided instruction Prosection	Online learning Prosection	
Mc Garvey et al.	2015	Ireland	Nursing	Prosection Plastination	Prosection Plastination	

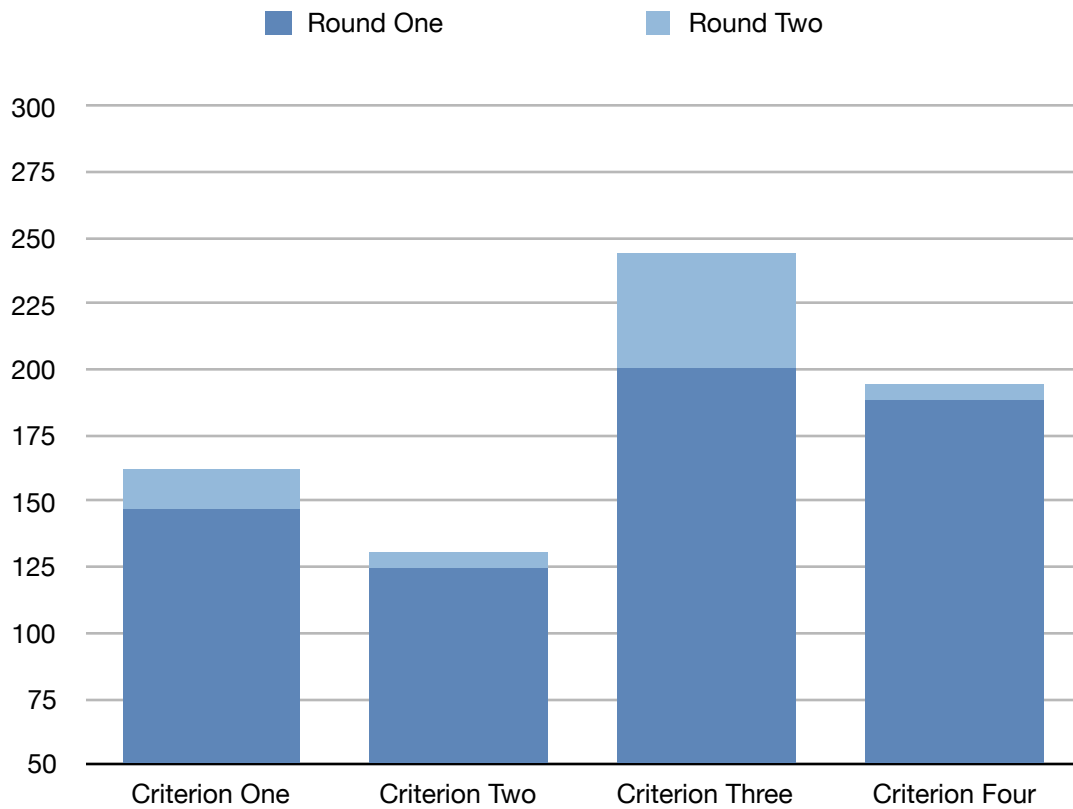
<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
McCulloch et al.	2010	United States	Medicine		Yoga and pilates	Musculo-skeletal system
Melovitz-Vasan et al.	2013	United States	Medicine		Team based learning	
Mitrousias et al.	2018	Greece	Medicine	Prosection Computer-aided instruction	Prosection 3D computer model	Musculo-skeletal system (upper limb)
Mogali et al.	2018	Singapore	Medicine	Plastination	3D printed model Plastination	Musculo-skeletal system (upper limb)
Moro et al.	2017	Australia	Undergrad Medicine	Computer-aided instruction	Virtual reality Augmented reality 3D computer model	Head and Neck - Skull
Morton & Colbert-Getz	2017	United States	Medicine		Flipped classroom	
Moscova et al.	2015	Australia	Medicine	Medical imaging	Ultrasound X-Rays MRI scans CT scans	
Murakami et al.	2014	Japan	Medicine	Cadaveric dissection Medical imaging	Cadaveric dissection CT scans	
Musumeci et al.	2014	Italy	Medicine		Animal organ dissection	Heart
Naeger et al.	2013	United States	Medicine	Medical imaging	Peer teaching Ultrasound	Upper limb vasculature
O'Reilly et al.	2016	Ireland	Medicine	Cadaveric dissection	3D printed model Cadaveric dissection	Lower Limb
Oakes et al.	2018	Australia	Medicine	Medical imaging	Peer teaching CT scans	Abdomen
Oh et al.	2011	Korea	Medicine		Motor memory	Vessels, Nerves
Pais et al.	2017	Portugal	Medicine	Cadaveric dissection	Cadaveric dissection	
Pan et al.	2017	China	Medicine	Integrated curriculum	Integrated curricula	
Park & Howell	2015	United States	Dentistry		Flipped classroom	

<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Parmar et al.	2011	India	Physical Therapy Occupational Therapy		Case-based learning	Respiratory system
Peeler et al.	2018	Canada	Medicine	Cadaveric dissection Prosection	Cadaveric dissection Prosection	Musculo-skeletal system
Perumal	2018	New Zealand	Medicine	Medical imaging	Sectional anatomy learning tool	Thorax Abdomen Pelvis
Pickering	2015	United Kingdom	Medicine	Computer-aided instruction	Drawing, screencasts	Abdominal wall Pelvis
Pickering	2017	United Kingdom	Medicine	Computer-aided instruction	Drawing, screencasts	Lower limb - gluteal region
Pickles et al.	2019	Cambodia	Medicine Nursing		Peer tutoring	Cardio-respiratory systems
Pizzimenti et al.	2016	United States	Medicine	Cadaveric dissection	Cadaveric dissection	
Pujol et al.	2016	United States	Medicine	Computer-aided instruction	3D computer model	
Ramsey-Stewart et al.	2010	Australia	Medicine	Cadaveric dissection	Cadaveric dissection	
Rea & Linn	2017	United Kingdom	Medicine	Computer-aided instruction	Online learning	Heart Abdominal cavity Hand and wrist
Reilly, F. D.	2011	United States	Medicine		Interactive learning objects	
Rempell et al.	2016	United States	Medicine	Medical imaging	Ultrasound	
Resuehr & Makeeva	2015	United States	Medicine		Peer tutoring	
Rich & Guy	2013	Australia	Undergrad	Computer-aided instruction	Online learning	Musculo-skeletal system
Richardson-Hatcher et al.	2014	United States	Medicine	Computer-aided instruction	Online learning	Head and neck
Saalu et al.	2010	Nigeria	Medicine		Problem-based learning	

<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Serrao et al.	2017	Italy	Medicine	Living anatomy Medical imaging	Living anatomy Ultrasound	Musculo-skeletal system Thorax Abdomen Pelvis
Serrat et al.	2014	United States	Medicine		Self-directed learning	
Shaffer	2016	United States	Undergrad Nursing	System-based curriculum	Textbooks System-based teaching	
Siqueira Da Silva et al.	2017	Brazil	Physiotherapy	Computer-aided instruction	Augmented reality	Upper limb
Smith et al.	2018	United Kingdom	Medicine		3D printed model	
Smith et al.	2018	United States	Medicine	Medical imaging	Ultrasound	
Stewart & Choudhury	2015	United Kingdom	Medicine		eBook	Brachial plexus
Stirling & Birt	2017	Australia	Medicine		eBook	Heart and great vessels
Sweetman et al.	2013	Australia	Medicine	Medical imaging	Ultrasound	Abdomen
Swinnerton et al.	2017	United Kingdom	Medicine	Computer-aided instruction	Online learning	Abdomen Digestive system
Sytsma et al.	2015	United States	Medicine		Inter-professional learning Peer teaching Case based learning	
ten Brinke et al.	2014	Netherlands	Medicine	Cadaveric dissection	Cadaveric dissection	
Thomas et al.	2011	United States	Physical Therapy Occupational Therapy	Computer-aided instruction	Computer aided learning	
Thomas et al.	2010	United Kingdom	Medicine	Computer-aided instruction Cadaveric dissection	Augmented reality Cadaveric dissection	Brain - ventricles
Topping	2014	United States	Medicine	Computer-aided instruction	Videos	Thorax Abdomen Pelvis

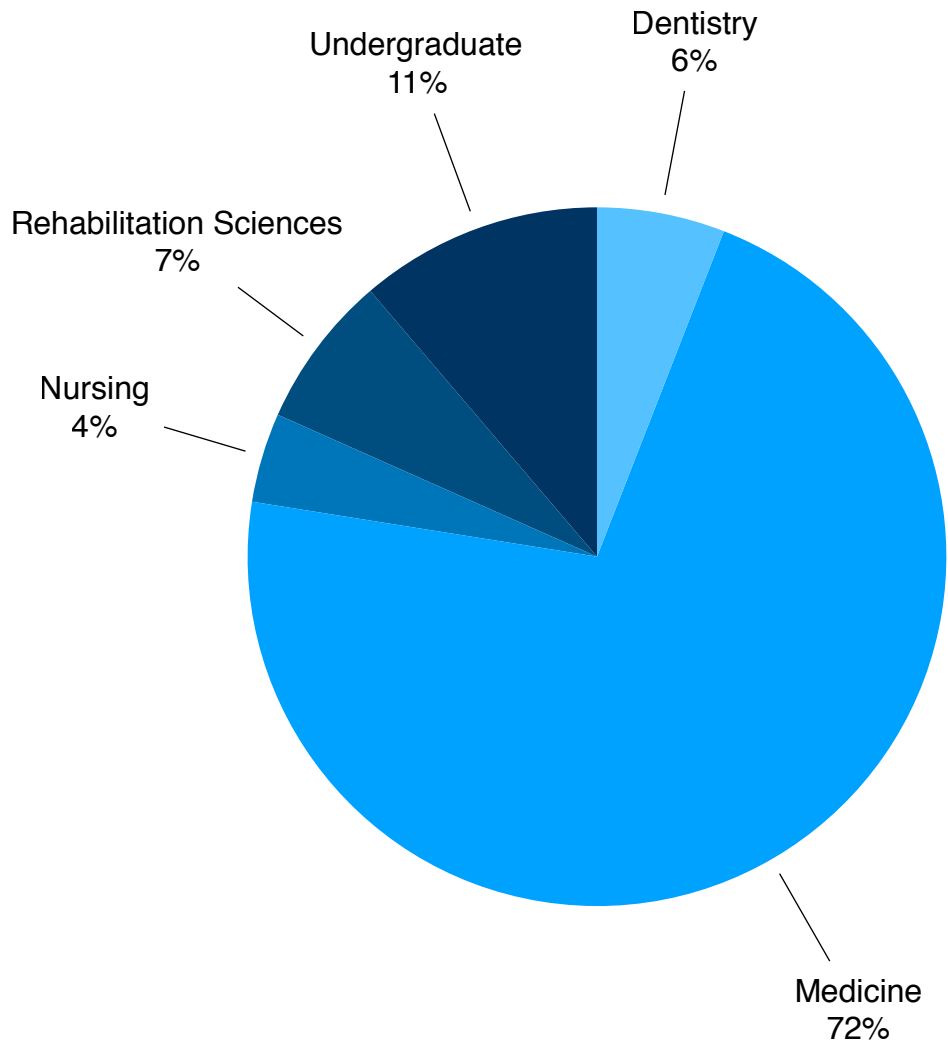


<b>Author(s)</b>	<b>Year</b>	<b>Country</b>	<b>Student Population</b>	<b>Classification</b>	<b>Tool Used</b>	<b>Specified Region / System</b>
Torres et al.	2016	Poland	Medicine	Medical imaging	Ultrasound CT scans	Abdomen Pelvis
Van Nuland & Rogers	2017	Canada	Undergrad	Computer-aided instruction	Computer aided learning	
Wang et al.	2010	China	Medicine	Cadaveric dissection	Problem-based learning Cadaveric dissection	
Waters et al.	2011	United States	Undergrad Nursing		Clay modeling Animal-based dissection	
Wilkinson & Barter	2015	United Kingdom	Undergrad	Computer-aided instruction	Mobile devices	
Williams et al.	2019	United States	Medicine	Cadaveric dissection Prosection	Cadaveric dissection Prosection	Ankle and foot
Wright	2012	United States	Undergrad	Computer-aided instruction	Models Online learning	
Wu et al.	2018	China	Medicine	Medical imaging	3D printed model X-Rays CT scans	Spine Upper limb Lower limb Pelvis
Yeom et al.	2013	Australia	Medicine	Computer-aided instruction	Computer aided learning	
Yi et al.	2019	China	Medicine		3D printed model	Brain - ventricles
Zumwalt et al.	2010	United States	Medicine	Medical imaging	CT scans Ultrasound Models	



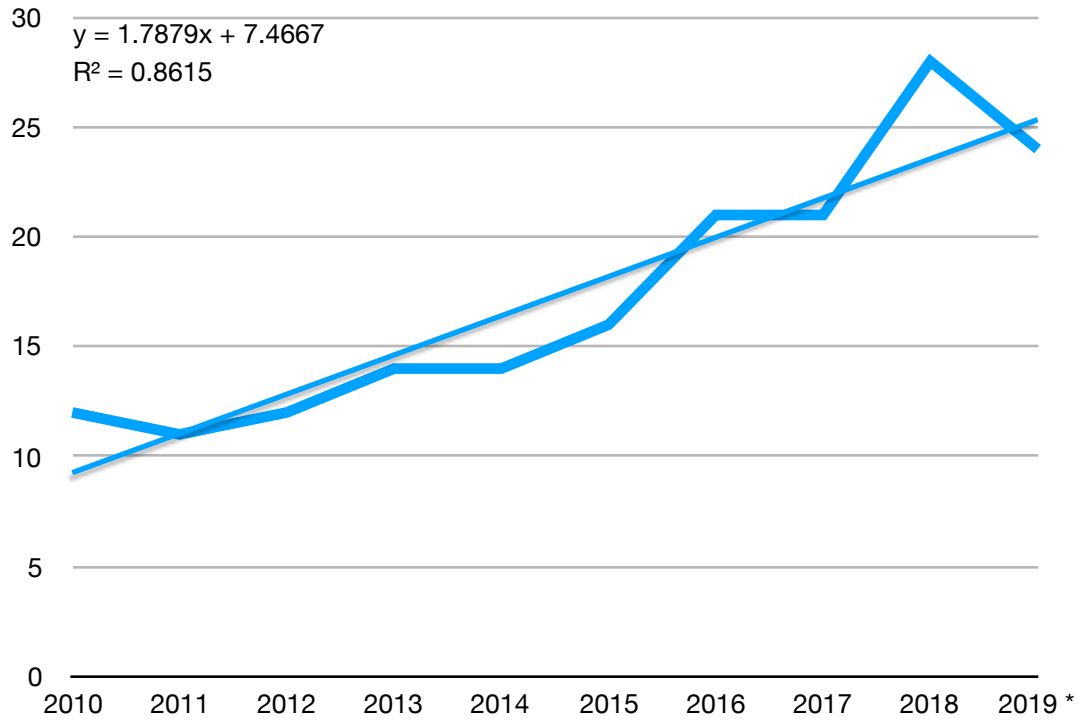
**Figure 2: Distribution of Rejection Criteria**

The number of papers rejected on each category in each of the two rounds are represented above. The lower, dark blue region represents the papers that were rejected on the basis of their titles and abstracts. The lighter blue region represents the papers that were rejected after a full text review. The majority of papers (60%) were removed on the final two rejection criteria because of the nature of the learning tool discussed in the paper, or the course being examined was not a purely anatomy course and contained other subjects like embryology and physiology.



**Figure 3: Proportion of Student Population**

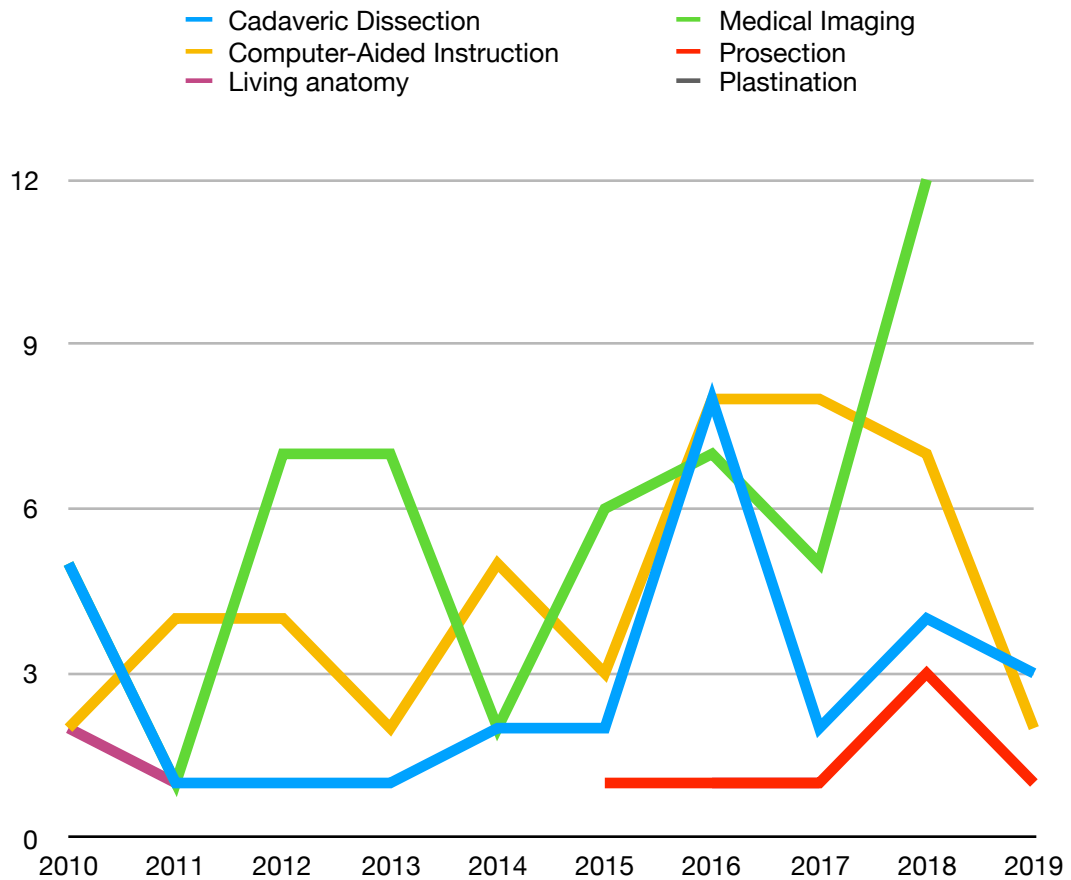
Medical students accounted for nearly three quarters of the total student population targeted. In seven articles (6%), medical students were combined with other student populations for the purposes of the educational intervention being explored. The remaining 115 articles that included medical students focused solely on medical students in isolation from other student populations. If a paper included a target intervention for multiple student populations, each student population was considered separately from the others.



**Figure 4: Total Number of Sources by Year**

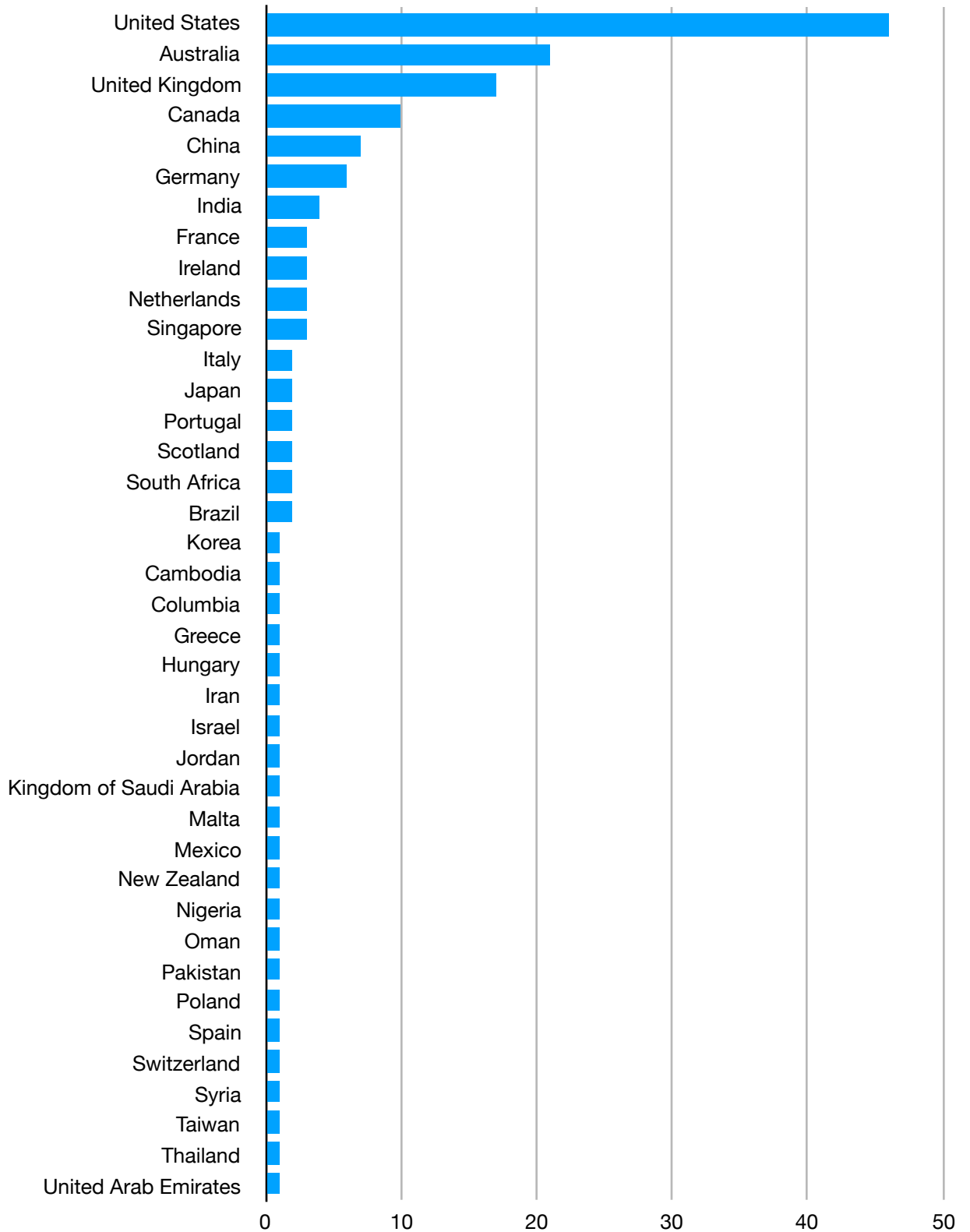
The total number of articles was charted by year of publication, and a trend line applied. An upward trend in the literature included for the scoping review suggests increased interest from scholars.

\* The value for publications in 2019 was estimated based on the number of publications from the first four months of the year (the cutoff for database searching was 30th April, 2019).



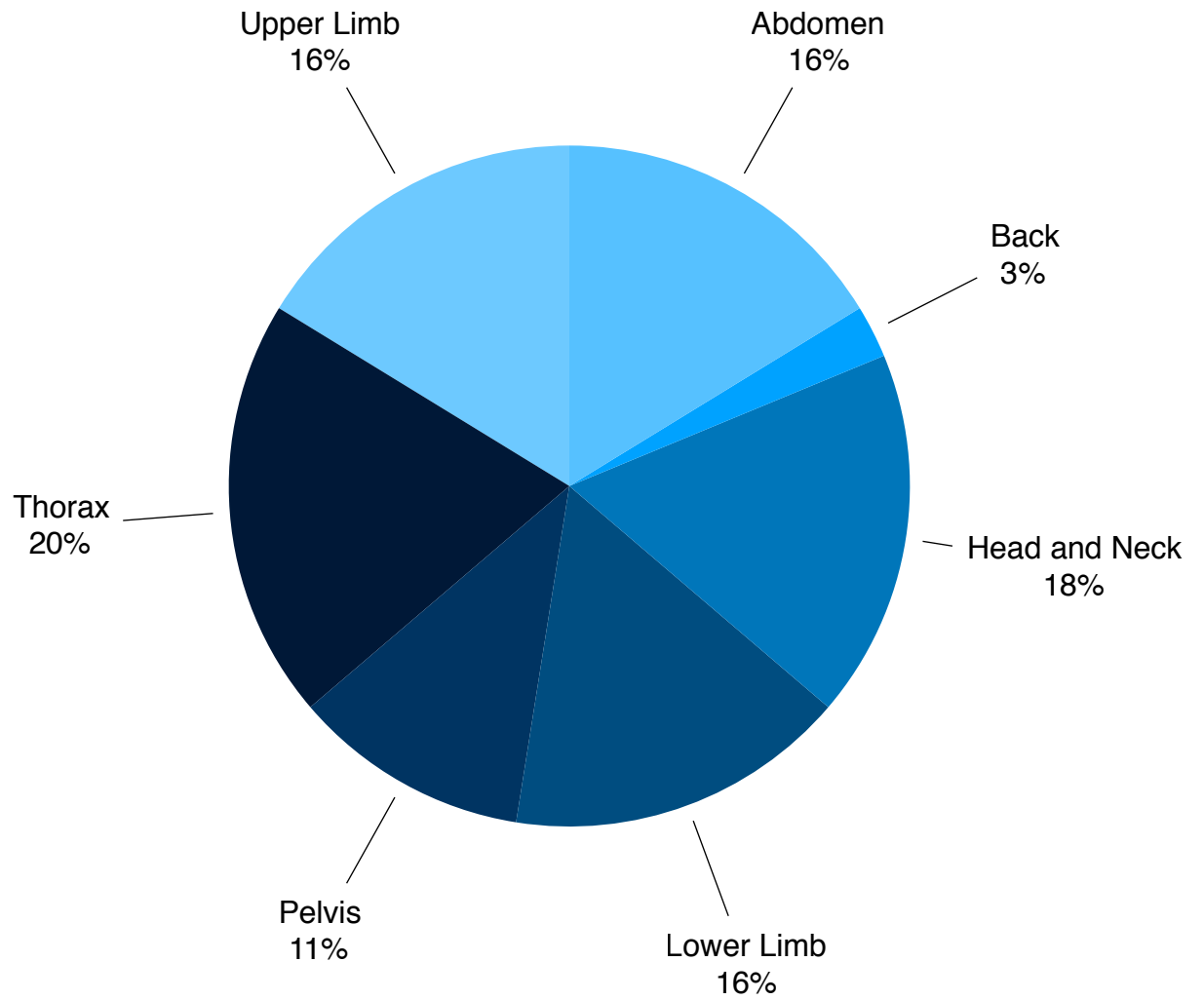
**Figure 5: Trends Across Educational Interventions by Year**

The year of publication of each study was matched to the categories offered by Estai and Bunt (2016) to examine the trends of publications year over year in each category. Cadaveric dissection remained constant throughout the scoping review period, except for one increase in 2016. Medical imaging and CAI both saw steady increases in the amount of attention they received in the captured research articles.



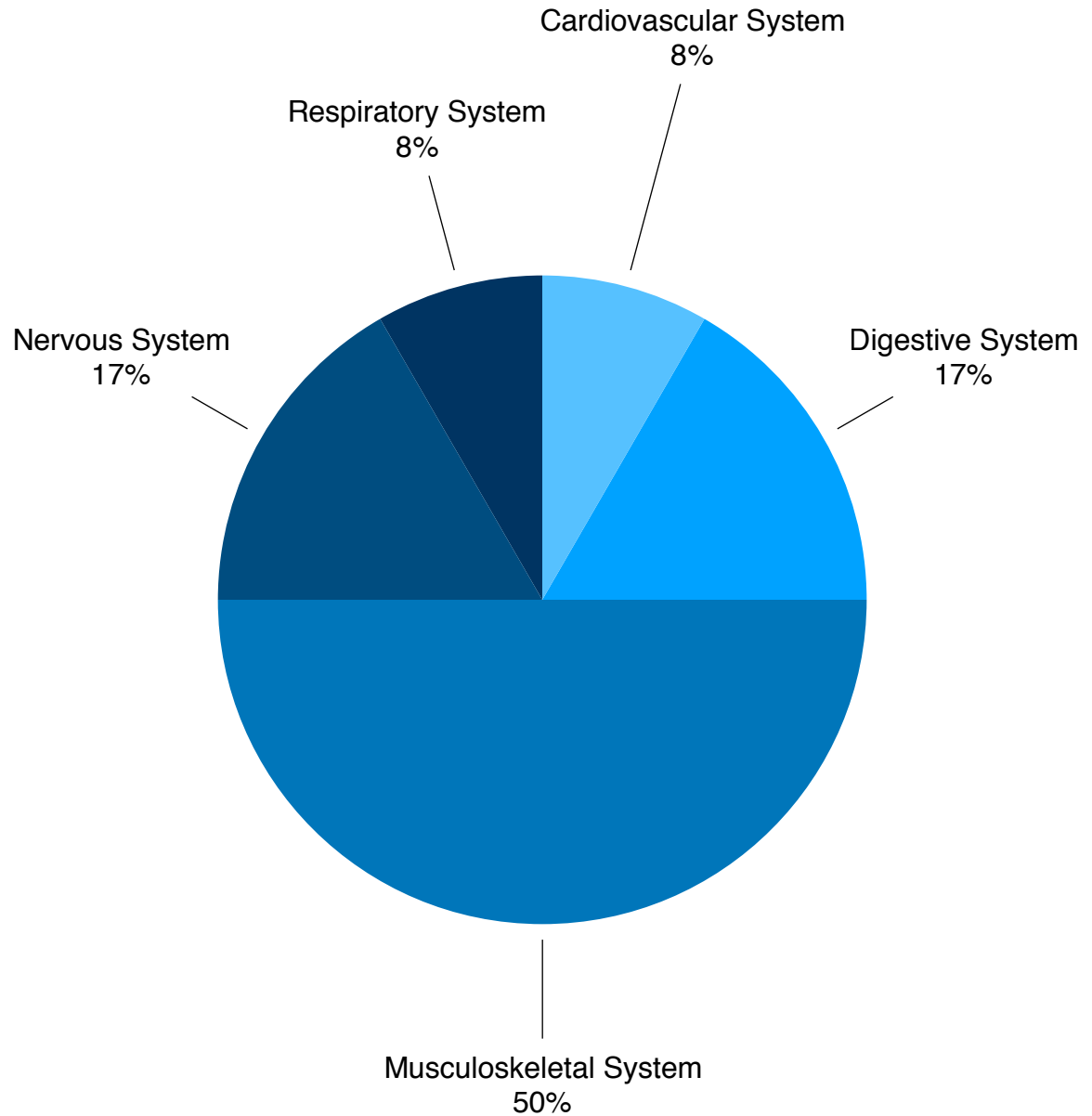
**Figure 6: Total Number of Sources by Country**

The top four countries of publication comprised 60% of the articles captured by the scoping review. Over 80% of the countries listed had three or fewer references, 56% had only one paper captured by the scoping review.



**Figure 7: Body Regions Targeted in Literature**

Eighty papers discussed the use of an educational intervention in the context of a regional-based anatomy course, and the different regions of the body showed a more balanced distribution than that of the systems-based approach.



**Figure 8: Body Systems Targeted in Literature**

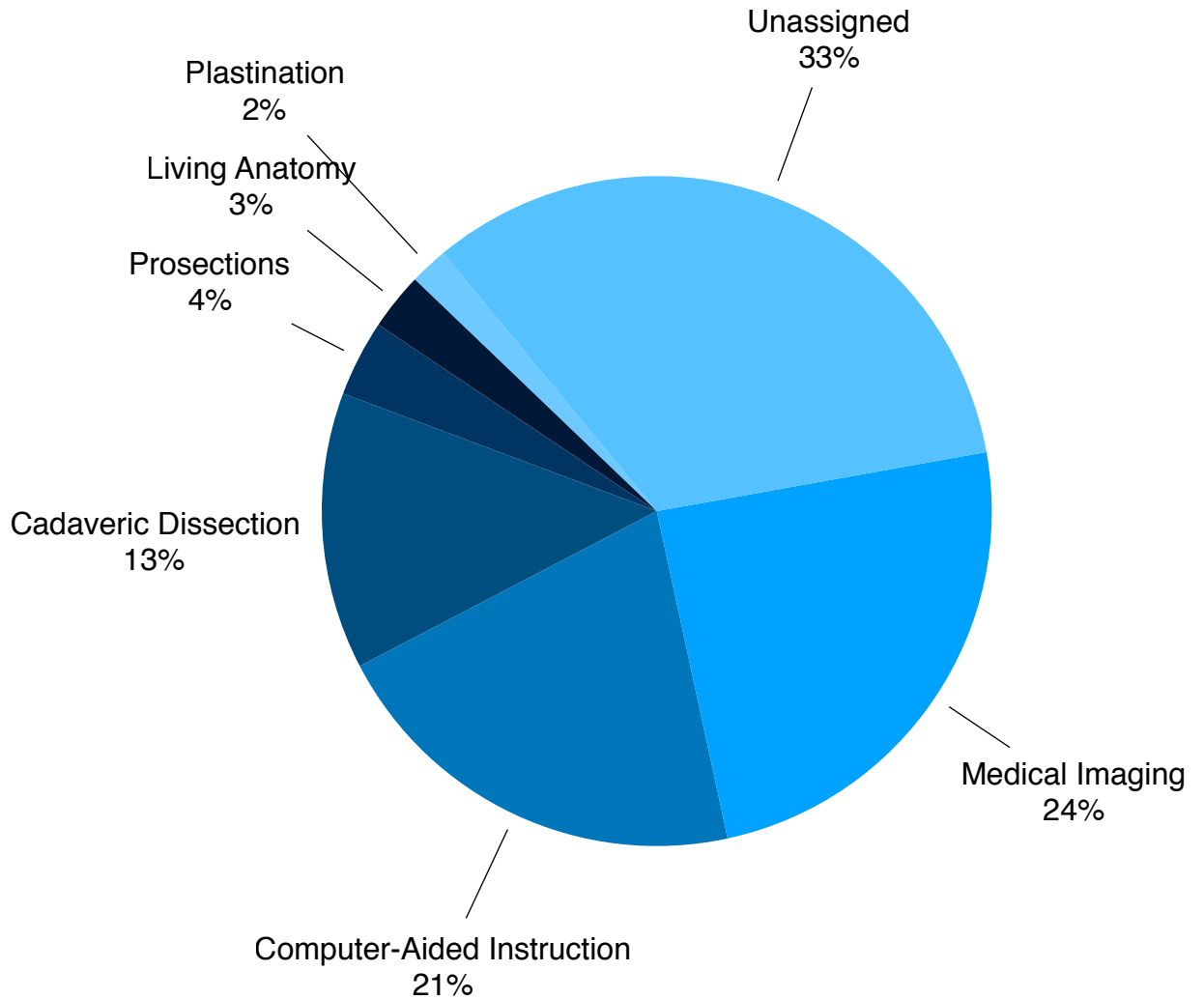
Only eight papers implemented an educational intervention in a clearly system-based curriculum. The high prevalence of the musculoskeletal system may correspond to it receiving more attention in the anatomy curricula, or may relate to the relative difficulty of the system compared to others. In some instances, multiple systems were targeted by the same intervention.



**Table 2. Cross Referencing Educational Tools by Student Population**

	Medicine	Nursing	Undergraduate	Rehab	Dentistry
<b>Cadaveric dissection</b>	24	1	1	2	3
<b>Prosections</b>	5	1	0	2	0
<b>Plastination</b>	2	1	0	0	1
<b>CAI</b>	28	0	12	8	3
<b>Medical Imaging</b>	50	0	2	0	2
<b>Living Anatomy</b>	6	0	1	0	1
<b>Lecture-Based Learning</b>	0	0	0	0	0
<b>System-Based Learning</b>	0	1	1	0	0

Multiple interventions per student population were used in some studies. This table does not include interventions with unassigned categories. The Integrated Curricula category offered by Estai and Bunt (2016) is not included in this table because of its specificity to medical student education



**Figure 9: Percentage of Category**

Medical imaging, CAI, and cadaveric dissection were the largest categories represented in the literature. Plastination, living anatomy, prosections, system-based curricula, and integrated curricula represented approximately one-tenth of the included literature. The remaining literature could not be sorted into one of the categories and were therefore classified as “unassigned.”

\* Integrated curricula, system-based curricula, and lecture based learning were not included in the chart.

## Discussion

Based on the growing body of literature around anatomy education, one would expect to see significant changes in anatomy education (Vorstenbosch et al., 2011). However, it is clear from this review that most of the literature is focused on teaching anatomy to professional students, mostly medical students.

Cadaveric dissection seems to remain the primary teaching method for anatomy, as it has in the last four centuries. Learning anatomy through the use of human cadavers is a complex learning experience, and has aspects that are not easy to quantify or objectively evaluate (Winkelmann, 2007). The use of cadaveric material (dissection, prosection, and plastination) as an educational tool represented almost two-thirds of the included literature. What is less clear is whether or not it will remain the highest standard of anatomy education. Despite the apparent quality and efficacy of using cadavers to teach anatomy, their use is still on the decline because of other pressures such as budget cuts, donor shortages, and lack of staff. While there was a consistent number of publications surrounding the topic of cadaveric dissection as an educational intervention, a number of publications discussed changes in curricula which phased out cadaver-based instruction. In the face of rapidly developing alternative teaching strategies, more attention is being given to CAI, and the results of this scoping review suggest that as cadaveric dissection continues to be subjected to increased budget and resource restrictions, CAI will likely take its place.

Within the field of anatomy education, commercial e-learning tools have capitalized on the assumption that new technologies are at least as effective as traditional methods, and their implementation into anatomy curricula has outpaced objective evidence regarding their effectiveness (Van Nuland & Rogers, 2017). When implementing technology into the classroom setting, it is imperative that pedagogy precede technology (Hanna, 2014). Generally, these new teaching methods and pedagogies are aimed at reaching larger class sizes with fewer contact hours and resources to do so. Anatomy educators must maximize the information transferred

to students with limited resources, while promoting an accurate, three-dimensional understanding of the human body (Lewis, Sagmeister, Miller, Boissaud-Cooke, & Abrahams, 2016). Time constraints are just one factor impacting the decision to use different teaching modalities, others include staff requirements, costs, educational impact, and student acceptance (Griksaitis et al., 2012). Therefore, many of the newer teaching strategies are created with efficiency and expediency in mind. For this reason, CAI approaches to learning anatomy may have an inherent advantages over other teaching methods.

Some ponder whether or not continual budget and resource restrictions will eventually phase out cadaveric dissection from the anatomy curriculum (Pawlina & Lachman, 2004). If this does become the case, it is contemplated whether or not an anatomy course can fulfill its objectives if dissection is no longer offered to students (Granger, 2004). The results of this scoping review suggest that the loss of cadaveric dissection would only negatively affect a small number of students whose careers will demand the most amount of anatomy knowledge, such as future surgeons.

Many scholars believe that a good understanding of anatomy depends upon learning concepts and managing information for solving problems, rather than just memorization (Johnson et al., 2012). The acquisition of anatomical knowledge is a complex process, and is therefore difficult to study objectively (Winkelmann, 2007). Anatomy learning goes through a process of learning, forgetting, restructuring, and applying (Smith & Mathias, 2011). To master anatomy, one must be able to understand three dimensional relationships (Bareither et al., 2013). Learning spatial relationships in anatomy is a difficult feat (Miller, 2000). Students must learn orientation, location, and structural dimension, and retain that information (Bareither et al., 2013).

Learning theory dictates that recall is promoted by learning concepts in the context that they will be used (Rizzolo et al., 2006). The context in which most anatomy knowledge will be employed is in a clinical, patient-focused setting. Clinical

relevance aids anatomy learning (Dusseau et al., 2008). This may partially explain the increased use of medical imaging to instruct students in anatomy, since it represents a tangible link between anatomy that is learned in a class setting and the way it is often presented in professional practice. The growth in medical imaging and minimally invasive surgical techniques requires a sound understanding of anatomy in three dimensions (Knobe et al., 2012). Therefore, teaching students anatomy in a similar manner as that encountered in clinical practice improves patient outcomes and makes anatomy more relevant to students.

Overall, the types of anatomy education modalities put forth by Estai and Bunt (2016) represented the majority of the literature, except for the 33% of the educational approaches that could not be classified (Figure 9). Each category is discussed in the following sections.

## **Cadaveric Dissection**

Cadaveric dissection was found to improve student attention (Aversi-Ferreira, do Nascimento, Vera, & Lucchese, 2010) and learning (Aversi-Ferreira et al., 2010; Burgess & Ramsey-Stewart, 2015; Marshak, Oakes, Hsieh, Chuang, & Cleary, 2015; ten Brinke et al., 2014). Students have been found to perform better on anatomy examination questions pertaining to regions they have actively dissected (Pizzimenti et al., 2016), though the effect might be smaller than widely believed (Marshak et al., 2015).

Cadaveric dissection can improve practical skills, as well as anatomy knowledge (Larkin & McAndrew, 2013). It can also contribute to professional skills. The chance to experience death in a controlled environment is an important learning opportunity for students offered by cadaver labs (Mc Garvey et al., 2015). This effect is valuable for any healthcare professional student, and has been demonstrated with nursing student populations as well (Mc Garvey et al., 2015).

Many scholars still argue for the importance of cadaveric dissection in anatomy curricula (Aversi-Ferreira et al., 2010; Pais et al., 2017; Ramsey-Stewart et al.,

2010), in both undergraduate and graduate contexts (Barton, Williams, Halle, & McGrew, 2018). However, as the medical curriculum in particular continues to evolve, cadaveric dissection is reduced or removed altogether (Bohl, Francois, & Gest, 2011). Only a few studies included in the scoping review examined cadaveric dissection in isolation from other teaching modalities. Many of the studies that included cadaveric dissection aimed to link it with medical imaging or CAI to further augment its utility. These studies often compared the alternative method to cadaveric dissection, seeking to understand if it could one day replace cadaveric dissection altogether.

Some papers discuss alternatives to anatomy dissection. For example, 3D printing of anatomical structures provides a valuable adjunct to handling cadaveric material related to the heart (Lim, Loo, Goldie, Adams, & McMEnamin, 2016) and lower limb (O'Reilly et al., 2016). Animal-based dissections appeared twice in the literature included for review (Musumeci et al., 2014; Waters, Van Meter, Perrotti, Drogo, & Cyr, 2011). In both instances, they served as a viable alternative for human cadaveric dissection. However, it was not recommended that animal-based models replace cadaver labs (Musumeci et al., 2014). Nevertheless, animal dissections have merit.

Small group learning that occurs in the cadaver lab, complemented by digital web based learning, has been found to be a pragmatic and cost effective way to improve anatomy learning for students (Thomas, Denham, & Dinolfo, 2011). Further use of combined methods such as this may help make cadaveric dissection a more appealing method to teachers.

Teaching anatomy to large numbers of students in a dissection lab requires a multitude of skilled instructors (Horneffer et al., 2016), as well as specialized equipment and embalming tools. This makes it one of the most resource intensive teaching strategies available to instructors. It is also very technical and demanding. With novice dissectors, some structures can become disfigured, thereby eliminating or significantly reducing the ability for a student to appreciate those structures

(Carter et al., 2017). So while it is regarded as one of the best teaching methods for anatomy, cadaveric dissection is not a flawless modality and is perhaps not suitable for all anatomical education environments.

## **Prosections**

Williams and colleagues (2019) found that the use of prosections was better suited to learning anatomy of the hand and foot rather than dissection of those regions. For physical and occupational therapy students, neither actual dissection or faculty led demonstration proved superior to the other (Kinirons, Reddin, & Maguffin, 2018). By determining which regions of the body may best be learned from prosections rather than dissection may alleviate resource and time constraints of full body cadaveric dissection (Williams et al., 2019), thereby retaining the place of cadaveric material use in anatomy education with increasing limitations surrounding it.

When prosection and dissection were compared against each other, students viewed both learning experiences as positive and valuable (Peeler et al., 2018). Unfortunately, prosection demonstrations may deprive students the hands on experience that cadaveric dissection offers and that kinaesthetic learners thrive on for their learning (Carter et al., 2017). In this regard, it may not be as effective of a learning tool than cadaveric dissection, but it does not require the same technical skills of the learner that the process of dissection demands.

## **Plastination**

Medical schools are replacing cadaveric dissection labs with prosected materials, plastinated prosections, plastic models, imaging, and digital models (Mogali et al., 2018). Compared to prosections and dissections, plastinated specimens offer increased strength and longevity, and no odours (James, Chapman, Dhukaram, Wellings, & Abrahams, 2018). These specimens will retain their original structure and can be handled safely (James et al., 2018). These features make plastination a promising technique for teachers, as they are less maintenance and can be used with more students over a longer period of time than either dissection or prosection.

Similar to prosections, the educational value of plastination may depend on the region of the body being explored or taught. For example, using plastinated specimens sliced along a sagittal plane is useful for teaching anatomy of the foot and ankle, and provides a connection between anatomy and radiology (James et al., 2018). It is suggested that plastination can be a successful replacement for cadaveric dissection (Baker, Slott, Terracio, & Cunningham, 2013), but this claim may require more support in the literature before it can be widely accepted. As cadaveric dissection is used less often, plastinated specimens may eventually become the only avenue for student interaction with cadaveric material, but this would likely be caused by restricted resources rather than educational merit.

## **Computer-Aided Instruction**

Students have generated a demand for academic material to be delivered through electronic mobile devices, not just through traditional methods (Stewart & Choudhury, 2015). There is a huge potential for the use of these novel technologies in anatomy education (Alfalah et al., 2018).

The benefits of CAI may be specific to the body system or region being taught. For example, a high fidelity model of the larynx offered no benefit for long term retention over a low fidelity model (Fritz et al., 2011), and a 3D model of hepatobiliary anatomy neither enhanced nor inhibited student learning compared to a more traditional textbook approach (Keedy et al., 2011).

## **Augmented Reality and Virtual Reality**

Both Virtual Reality (VR) and Augmented reality (AR) have been supported by the literature for the purposes of teaching anatomy (e.g., Bork et al., 2019; Kelly et al., 2018; Moro, Stromberga, Raikos, & Stirling, 2017; Siqueira Da Silva, Klein, & Brandao, 2017). They can increase spatial understanding, particularly in students with low spatial ability (Bork et al., 2019), enhance student learning experiences (Kelly et al., 2018), and increase student engagement (Moro et al., 2017).



Students who used VR to study heart anatomy found it to be highly satisfying compared to traditional methods (Alfalah et al., 2018). A similar study found that VR was an immersive and intuitive experience for students to appreciate the structures of the heart, and was able to increase student performance (Maresky et al., 2019). Similar results were seen in a study where VR was used to teach forearm anatomy, but the authors caution against it replacing traditional methods (Codd & Choudhury, 2011). Augmented Reality allows for student-centred learning and motivates students to learn anatomy with an appreciation for its three dimensional nature (Kugelmann et al., 2018). Thomas and colleagues (2010) used AR technology alongside cadaveric dissection to improve student understanding of the ventricular system of the brain, finding it to be a useful adjunct for students.

The future of anatomy education could be based on AR (Ferrer-Torregrosa et al., 2015). Some authors argue that AR could replace the use of two dimensional atlases (Siqueira Da Silva et al., 2017). Likewise, as VR becomes more cost effective, it may become a more enticing teaching strategy for instructors (Maresky et al., 2019).

### **Mobile Devices**

Another form of CAI is mobile learning. The use of mobile technologies among students in learning contexts is growing to the point of ubiquity, thereby forcing educators to reexamine its merits (Lazarus, Sookrajh, & Satyapal, 2017). The use of tablet devices was found to have a positive effect on learning outcomes (Lazarus et al., 2017; Wilkinson & Barter, 2015), as well as student attendance (Wilkinson & Barter, 2015). Mobile devices such as tablets can also enhance and facilitate group learning (Wilkinson & Barter, 2015). The use of mobile devices also works well when exploring medical imaging. For example, the use of iPads to view CT imaging was met with positive reception from students (Murakami et al., 2014).

### **Blended Learning, Flipped Classrooms, and Online Learning**

An alternative to pure lecture based learning is blended learning (Estai & Bunt, 2016). This method utilizes the combination of traditional face to face lectures and online learning (Kharb & Samanta, 2016). The use of blended learning is well suited to anatomy courses (Green & Whitburn, 2016). Blended learning provides students the best possible learning and teaching experiences while simultaneously supporting teachers in their role as facilitators. (Kharb & Samanta, 2016). The use of blended learning can help instructors overcome the time constraints of a typical classroom (Kharb & Samanta, 2016). The overarching goal of a flipped classroom or blended learning is to achieve a more student-centred learning environment through active and collaborative learning (Park & Howell, 2015). The use of online resources and blended learning is able to reach students with different learning styles, background knowledge, and interest (Wright, 2012). However, the efficacy of this type of learning tool may be limited by the self-discipline of the student (Mathiowetz, Yu, & Quake-Rapp, 2016).

Student use of online forum discussion was found to be associated with higher academic achievement (Green, Farchione, Hughes, & Chan, 2014; Green & Hughes, 2013; Green & Whitburn, 2016; Wright, 2012). The use of online forum discussion may encourage higher level learning outcomes (Green & Hughes, 2013). The time taken to develop and maintain online course content is worthwhile, offers improved student learning outcomes, and does not negatively impact student engagement or satisfaction (Green & Whitburn, 2016).

The use of online materials to aid anatomy instruction is intriguing. It is a resource that is readily available to students and is easily managed by teaching staff, but its effectiveness depends on the motivation of the student to access those materials. Attardi and colleagues (2016) found that students appreciated the control and flexibility afforded to them through the use of online materials. However, students still preferred face to face instruction, as they found it more engaging and had fewer distractions (Attardi et al., 2016). Blended learning should not be a simple matter of combining methodologies without clear pedagogical goals (Park & Howell, 2015). It

is important for instructors to maintain a clear set of learning outcomes for their students, regardless of the teaching modalities used. Finally, the use of online learning tools deprive students the hands-on experience typically associated with learning anatomy.

### **Three Dimensional Computer Models and Graphics**

Three dimensional visualization techniques and animations are supported by the literature (e.g., Fleagle, Borcharding, Harris, & Hoffmann, 2018; Hoyek, Collet, Di Rienzo, De Almeida, & Guillot, 2014) and appreciated by students (Mitrousias et al., 2018). Three dimensional animations facilitate the comprehension of spatially demanding anatomical knowledge (Hoyek et al., 2014). Compared to prosections, 3D software is more accessible and requires fewer resources (Mitrousias et al., 2018).

Three dimensional computer graphics can have a positive impact on student learning when properly integrated into conventional curricula (Battulga, Konishi, Tamura, & Moriguchi, 2012). For example, three dimensional visualizations of hepatobiliary anatomy were compared to 3Dp material, and each had the same effect on student learning and satisfaction (Kong et al., 2016).

### **Audiovisual Materials**

The use of digital audiovisual resources to prepare students for dissection was found to significantly improve student examination results (Choi-Lundberg et al., 2016) and student satisfaction (Ahmad et al., 2016). Audiovisual materials are also typically well-received by students (Topping, 2014). Even Youtube has found a place in anatomy education, owing to the platform's popularity among students (Jaffar, 2012).

### **Digital Textbooks**

Digital textbooks are effective in terms of usability, student satisfaction, and content (Stirling & Birt, 2014). They can be used alongside traditional methods of anatomy

teaching to enhance and promote deeper learning (Stewart & Choudhury, 2015; Stirling & Birt, 2014), and reduce teacher loads (Stirling & Birt, 2014).

iBooks, a form of digital textbook, was a successful resource for students, as it helped them learn content in a fun and interactive manner (Stewart & Choudhury, 2015). Digital textbooks might not be able to outperform traditional methods, but they are well received by students for their user experience (Stirling & Birt, 2014). Therefore, they work well as an adjunct or supplement to compliment other forms of anatomy teaching.

## **Medical Imaging**

Medical imaging is becoming increasingly relevant in today's healthcare system (Bork et al., 2019). Therefore, it follows that the findings of the scoping review suggest medical imaging is becoming more prevalent. This was reflected in the increasing attention given to medical imaging year over year (Figure 5). Along with CAI, medical imaging was one of the only categories to show an increased prevalence in the included literature over the ten year period of this scoping review.

A strong working knowledge of anatomy is critical for students to learn radiology (Arya, Morrison, Zumwalt, & Shaffer, 2013). Integration of anatomy and radiology is a useful and valuable addition to the standard anatomy course (Dettmer et al., 2013; Machado, Barbosa, & Ferreira, 2013). The use of imaging techniques represents a viable contribution towards anatomy instruction (Kolossvary et al., 2017). The early integration of medical imaging may facilitate understanding radiology in later years of study (Buenting et al., 2016). Teaching radiology with anatomy can provide students with new perspectives in anatomy while simultaneously making them more aware of the clinical importance of anatomy (Dettmer et al., 2013). Demonstration of anatomy via imaging tools helps promote an appreciation of the clinical relevance of anatomy (Griksaitis et al., 2012; Ivanusic et al., 2010).

### **X-Rays, CTs, and MRIs**

The use of an online medical imaging resource is favourably received by students (Marker, Bansal, Juluru, & Magid, 2010; Marker, Juluru, Long, & Magid, 2012). Small group, hands-on teaching model for radiological anatomy was perceived as useful for students and teachers alike (Torres et al., 2016). Images from X-Rays, CT scans, and MRI scans are often included in didactic lectures, but simply including these images in lectures does not make the imaging tools accessible to students (Carter et al., 2017).

One paper suggested that teaching anatomy solely with CT images is feasible (Kolossvary et al., 2017). However, others argue that medical imaging may not be able to completely replace cadaveric dissection. For example, Bohl and colleagues (2011) found that CT images were not a suitable substitute for cadaveric dissection of the heart.

### **Ultrasonography**

Like CTs and MRIs, ultrasound has become increasingly important in clinical contexts (Smith, Kendall, & Royer, 2018b). It has been shown to be beneficial to undergraduate, medical, and dental students alike (Ivanusic et al., 2010). What is particularly beneficial about learning anatomy with ultrasonography is the connection it applies between surface anatomy landmarks and associated deeper structures (Carter, Hocum, Pellicer, Patel, & Benninger, 2016).

Medical students feel it is practical and feasible to include ultrasound as a teaching tool in conjunction with traditional teaching methods (Brown et al., 2012a). They perceive it as valuable in understanding anatomy and learning physical exam skills (Rempell et al., 2016). Dental students also show satisfaction in the implementation of ultrasound in their anatomy curriculum, as it can provide a better understanding of maxillofacial anatomy (Kondrashova, De Wan, Briones, & Kondrashov, 2017).

The use of ultrasound to teach cardiac anatomy was found to be equivalent in quality to the use of cadaveric prosections and plastic models (Canty, Hayes, Story,

& Royse, 2015). The use of ultrasound may facilitate the learning of structural anatomy, and contribute to the interpretation of CT and MRI imaging (Carter et al., 2017). While students may view ultrasonography positively, it may not be enough to bridge the gap between traditional methods and clinical application (Sweetman, Crawford, Hird, & Fear, 2013). Simply including ultrasonography in an anatomy curriculum is not enough to make the course more clinically relevant, so care must be taken to ensure that students are properly trained in its use and how it facilitates patient-care in a clinical setting.

Some scholars argue that training anatomists to teach anatomy with ultrasonography could be useful in training future physicians (Jurjus et al., 2014). Further arguments exist that ultrasound should be an essential component of future physician training (Serrao et al., 2017).

### **Medical Imaging and Cadavers**

In some cases, cadaveric dissection was preceded by CT scans, such that both aspects could be used by the students (Bohl et al., 2011; Buenting et al., 2016; Lufner et al., 2010; Murakami et al., 2014). Moreover, CT images were directly compared to dissections and found to be of equal educational value (Kolossvary et al., 2017). This is also seen in studies where ultrasound training is done on cadavers used for dissection (e.g., Abed Rabbo, Garrigues, Lefevre, & Seizeur, 2016) and dissection (Griksaitis et al., 2012). Finally, X-Ray images on cadavers are perceived as beneficial by medical students (Kotzé, Mole, & Greyling, 2012).

### **Living Anatomy**

Body painting was a common teaching method for the living anatomy category. With this technique, different structures such as bone, muscle, vessels, and nerves are painted on to a living body (Jariyapong, Punsawad, Bunratsami, & Kongthong, 2016). The main advantage of body painting seems to lie in the creation of memorable and vivid experiences for students (Finn & McLachlan, 2010).

It is regarded as highly motivating for students, and is useful in large group settings (Finn & McLachlan, 2010). The use of body painting allows students to simultaneously learn anatomy and practice their professional skills (Finn & McLachlan, 2010). For example, it helps train students on how to respectfully work with patients in sensitive areas of their body, and provides deeper understanding to how clinical work on the surface of the body correlates to deeper structures (such as using a stethoscope to listen to the heart and lungs).

## **Lecture-Based Learning**

Alongside cadaveric dissection, lectures have been a key component of anatomy education (Vázquez et al., 2007). Some argue that no matter which methods are used to provide lectures to students, the impact of the learning session is highly dependent on the lecturer (Jarral et al., 2017). Changes in classroom structure have been driven by pedagogy and resources (Estai & Bunt, 2016). Scholars and educators continue to look beyond the lecture hall to make learning more interactive, engaging, and impactful for students.

## **Integrated Curricula**

Integrated curricula, where basic sciences and clinical medicine are taught together, have been in use for the last four decades (Pan, Cheng, Zhou, Li, & Yang, 2017). Integrated curricula have been shown to improve the analytical abilities of medical students (Pan et al., 2017). Longitudinal integration of medical imaging in anatomy education may improve student confidence in understanding imaging modalities and their clinical importance (Moscova, Bryce, Sindhusake, & Young, 2015).

## **System-Based Curricula**

Learning anatomy by system is viewed as easier than a region based approach, since learners can master one system at a time (Estai & Bunt, 2016). Furthermore, students can better retain factual information and can more easily relate that information to clinical practice (Estai & Bunt, 2016).

## **Alternative Teaching Methods**

### **Three Dimensional Models**

Three dimensional models can serve as an alternative to cadaveric dissection or prosection (Zumwalt, Lufler, Monteiro, & Shaffer, 2010), or as a supplement to cadaver-based curricula (Lim et al., 2016). Unlike cadaveric specimens, 3D teaching materials can be amassed, stored, and kept on a more permanent basis (Brown, Hamilton, & Denison, 2012b), which makes them more cost effective.

Dynamic visualization of three dimensional models may be a solution to the challenges of static, traditional teaching methods (Berney, Bétrancourt, Molinari, & Hoyek, 2015), such as textbooks and lectures. Stereoscopic representations of three dimensional models provide better representation of structural relationships than two dimensional models of the same material (Cui, Wilson, Rockhold, Lehman, & Lynch, 2017). Three dimensional stereoscopic models may improve anatomy performance, in particular for students with lower spatial ability (Cui et al., 2017).

### **Three Dimensional Printed Models**

3D printing (3Dp) is an innovative method of teaching anatomy (Lim et al., 2016) and a powerful teaching aid (Yi et al., 2019). Three dimensional printed models offer several benefits over cadaveric dissection, such as cost, ethics, and hygiene (Chen et al., 2017). They are an excellent learning tool, and serve as a valuable adjunct to cadaveric dissection or plastinated prosections (Mogali et al., 2018). However, students feel that 3Dp models are not as realistic as plastinated prosection (Mogali et al., 2018; Smith, Tollemache, Covill, & Johnston, 2018a). Therefore, they may not be able to completely replace cadaveric materials. Developing reliable methods for replicating the human body for the purposes of anatomy instruction is important (Cai, Rajendran, Bay, Lee, & Yen, 2018), and therefore 3Dp models are a valuable, emerging teaching tool.

Three dimensional models, particularly 3Dp models, are often derived from patient CT imaging data, such that they reflect real patient anatomy (e.g., Smith et al.,



2018a) and can also include aberrant anatomy, which is often missed in anatomy curricula. Three dimensional printed bone models may facilitate understanding of bone anatomy in complex sites, and may improve student satisfaction (Wu et al., 2018). Functional 3Dp modelling of joints can improve spatial anatomical understanding (Cai et al., 2018). The use of 3Dp models used to teach cardiac anatomy were found to significantly improve exam scores (Lim et al., 2016). Three dimensional printed skulls were helpful to students, compared to cadaveric skulls and atlases (Chen et al., 2017). They can elucidate complicated structures, like the ventricles of the brain (Yi et al., 2019). They were also shown to aid students in understanding complex pathologies such as vertebral fractures (Li et al., 2015).

### **Clay Modelling**

Clay modelling is increasingly being used to teach students (Kooloos, Schepens-Franke, Bergman, Donders, & Vorstenbosch, 2014). Students modelling anatomy with clay earned higher exams scores compared to students doing cat dissections (Waters et al., 2011). It is low cost, and involves kinaesthetic approach to learning (Kooloos et al., 2014).

### **Inter-Professional Learning**

Anatomy is well suited to inter-professional learning approaches, as it is essential to many health care professionals (Herrmann, Woermann, & Schlegel, 2015) and can be easily related between different professional tracks (Sytsma et al., 2015). An efficient healthcare system relies on key competencies such as teamwork and collaboration for safe patient care (Herrmann et al., 2015). Students in healthcare professions often receive adequate education for their own practice, but are left in need of more preparation for inter-professional collaboration (Herrmann et al., 2015). This provides another link between anatomy and patient outcomes, as well as professional competencies.

Inter-professional learning can have both immediate and long lasting effects on learners, and contributes to professional collaboration, teamwork, and communication (Sytsma et al., 2015). Using inter-professional education within the

anatomy classroom encourages collaboration and reinforces concepts that students learn in their respective disciplines (Sytsma et al., 2015).

### **Case-Based Learning**

Case-based learning (CBL) resources are a valuable adjunct to anatomy instruction (Holland & Pawlikowska, 2018). It is effective in teaching gross anatomy in a manner that is more interesting, integrated, and relevant (Jarral et al., 2017). Case-based learning has been demonstrated to improve academic test scores and better prepare students for clinical practice, and is welcomed by students (Parmar & Rathinam, 2011). While online CBL resources require considerable effort and time from staff in creating them, their use with subsequent student cohorts requires much less work and only minimal maintenance (Holland & Pawlikowska, 2018).

Case-based learning can help link theory to practice (Jarral et al., 2017). Anatomy seen in clinical settings often appear in the context of a patient case, and CBL prepares students on how to work through a case or problem in a guided environment.

### **Problem-Based Learning**

Problem-based learning (PBL) curricula are centred around the idea that the student is the central player, learning occurs in group discussions, and problems form the basis of teaching materials (Wang et al., 2010). The learning process in a PBL curriculum is more personal and engaging, improves learning efficiency, stimulates learning interest, and inspires students' initiative (Wang et al., 2010). In this regard, it is similar to CBL and team-based learning.

Problem-based learning has been shown to provide a significant improvement in student knowledge and confidence (Al-Madi, Celur, & Nasim, 2018). It promotes life-long learning by changing the aim of teaching from the delivery of professional knowledge to cultivation of the ability to learn (Wang et al., 2010). Problem-based learning can be a potent tool for long term knowledge retention and confidence (Al-Madi et al., 2018), and may be more beneficial than traditional methods of teaching

anatomy (Saalu, Abraham, & Aina, 2010). However, PBL alone might not be enough to ensure adequate learning of anatomy (Bergman et al., 2013). The most effective approach to PBL may involve pairing it with more traditional methods to maximize its effectiveness and student achievement of learning outcomes (Saalu et al., 2010).

### **Team-Based Learning**

Team based learning (TBL) is a teacher-directed approach that uses the application of knowledge in small group settings (Ghorbani, Karbalay-Doust, & Noorafshan, 2014). Team-based learning combines individual student preparation outside of the classroom with in-class discussion in small groups (Melovitz-Vasan, DeFouw, & Vasan, 2013). It aims to go beyond simply covering course content and instead ensures students use course concepts to solve problems that enhance student learning (Ghorbani et al., 2014). The TBL environment promotes active learning and deeper understanding (Inuwa, 2012).

Team-based learning as an education method results in improved knowledge gain and higher student satisfaction (Ghorbani et al., 2014). Students perceive TBL to be more rewarding and enjoyable than regular lecture-based teaching (Inuwa, 2012). Working in teams can improve student performance compared to working individually (Martinez & Tuesca, 2014; Melovitz-Vasan et al., 2013), and students tend to be more engaged in their learning with TBL, as the team environment facilitates active learning and peer teaching (Melovitz-Vasan et al., 2013). Team-based learning is highly applicable to cadaveric dissection labs, where students often work together dissecting the same body.

### **Inquiry-Based Learning**

Inquiry-based learning is defined as a range of strategies that promote student learning through independent investigation of questions, issues, or problems through the process of scientific inquiry (Lee, 2004, as cited in Anstey et al., 2014). It elicits authentic, meaningful learning experiences (Anstey et al., 2014). Students find their learning from IBL relevant and applicable to their exploration of anatomy in a creative and personally meaningful way, and can facilitate student development

and maintenance of intrinsic motivators such as self-regulated learning, autonomy, and responsibility for learning (Anstey, 2017).

### **Art and Drawing**

There is a strong association between art and medicine (Bell & Evans, 2014). The use of art to teach anatomy may contribute to observational skills (Bell & Evans, 2014). Drawing before or after dissection of a cadaver positively influences students comprehension of anatomy (Alsaid & Bertrand, 2016). The use of screencasts and drawings were well received among students (Greene, 2018) and may enhance learning compared to paper-based resources (Pickering, 2017).

### **Games**

Gamification of anatomy education can affect the learning process through altering student motivation, and results in better academic outcomes for student participants (Ang, Chan, Gopal, & Li Shia, 2018). Games may be a particularly effective vehicle for education, owing to their inherently interactive nature (Hill & Nassrallah, 2018). Anatomy games can allow learners to explore their knowledge strengths and deficits (Janssen, Shaw, Goodyear, Kerfoot, & Bryce, 2015). They have demonstrated to be engaging (Hill & Nassrallah, 2018; Janssen et al., 2015) and satisfying (Hill & Nassrallah, 2018); this is especially true when students can work together towards a common goal (Janssen et al., 2015). Furthermore, the introduction of organized competition via games can increase student motivation and academic outcomes (Van Nuland, Roach, Wilson, & Belliveau, 2015).

### **Peer Teaching, Peer Tutoring, and Peer-Assisted Learning**

Peer teaching can be a positive and beneficial experience for students (Agius et al., 2018; Bruno et al., 2016; Oakes, Hegedus, Ollerenshaw, Drury, & Ritchie, 2018). The use of peer assisted learning creates a favourable and fear-free learning environment for anatomy students (Horneffer et al., 2016). Peer teaching could be a valuable tool for teaching traditionally difficult health sciences courses to students (Bruno et al., 2016), such as anatomy. Peer teaching can improve educational outcomes while simultaneously managing the increasing demands placed on

faculty members (Agius et al., 2018). Furthermore, the use of this strategy does not necessitate increasing the number of professors or other salaried instructors (Resuehr & Makeeva, 2015), making it an attractive modality for anatomy instructors. The student tutors often receive formal training from instructors before tutoring other students, and tutors are often selected based on good academic standing (Christensen, Schmalz, Challyandra, & Stark, 2018).

Students with lower academic outcomes stand to gain more from peer teaching (Bruno et al., 2016; Hanna, Johnson, & Belliveau, 2015). Conversely, medical students who enrol in peer-teaching programs as teaching assistants gain valuable teaching experience for their future residencies (Resuehr & Makeeva, 2015). Peer tutoring is also useful for cadaveric dissection labs (Christensen et al., 2018; Dickman, Barash, Reis, & Karasik, 2017; Kinirons et al., 2018).

Similarly, near-peer teaching can allow faculties to meet the academic needs of a large number of students (Duran et al., 2012; Resuehr & Makeeva, 2015). Near-peer teaching is a similar approach to peer based learning, where students are taught by their classmates or more senior students, thereby drawing on a similar knowledge-base and set of experiences (Hall, Lewis, Border, & Powell, 2013, as cited in Dickman et al., 2017). It is effective in its ability to facilitate anatomy education in situations with limited resources and fewer staff members responsible for larger class sizes (Pickles et al., 2019). Both the learners and the student co-instructors find the experience of near-peer teaching to be valuable (Naeger, Conrad, Nguyen, Kohi, & Webb, 2013). Given the positive impact of near-peer teaching, it seems appropriate to utilize it in a larger scale to enhance learning experiences (Dickman et al., 2017). The implementation of near-peer teaching programs in anatomy courses is strongly supported (e.g., Agius & Stabile, 2018).

### **Self-Directed Learning**

Supported self-directed learning (SDL) approaches can be beneficial for anatomy teaching and lead to improved and deeper understanding of anatomy knowledge (Findlater, Kristmundsdottir, Parson, & Gillingwater, 2012; Serrat et al., 2014). This

has been demonstrated through improved student exam scores (Findlater et al., 2012). Self-directed learning projects are high yield, low cost solutions to teaching anatomy in resource-limited institutions or programs (Serrat et al., 2014). This method can be adapted to accommodate different time, space, and curricular restrictions as needed (Serrat et al., 2014).

Independent study is another form of SDL. Structured independent learning may improve long term retention of anatomy course content compared to unguided self study (Serrat et al., 2014). Furthermore, independent study and SDL promote life-long learning in students (Serrat et al., 2014), which is important for maintaining professional competency in healthcare practitioners.

### **Physical Exercises**

The inclusion of physical exercise and body awareness is a valuable adjunct to anatomical education (McCulloch, Marango, Friedman, & Laitman, 2010). The use of procedural movement and motor memory can be useful for remembering difficult spatial arrangements of vessels and nerves through the use of hand and finger positioning (Oh, Won, Kim, & Jang, 2011).

### **Exploring the Exclusion Criteria**

The number of articles removed as irrelevant to the study is not surprising, given the broad nature of the search terms used across the three databases. By retaining a set of broad parameters and searching through a larger number of results by hand, it was expected that more relevant literature could be found and included in the analysis, rather than it remain hidden by the use of more specific search criteria.

The papers that were rejected on the first criterion often used anatomy in a purely clinical context, rather than its instruction in a classroom or educational setting. Along with the second exclusion criterion, this lends support to the idea that the clinical importance of anatomy cannot be dismissed, however the clinical domain of anatomy was not within the scope of this review.

Many of the papers rejected on exclusion criteria two focused on training residents, particularly surgical residents, in anatomy. Again, an analysis of this population lay beyond the scope of this paper. However, it is interesting to note the close tie between anatomy and surgery, and offers more evidence of the importance surgical training places on sound anatomy education. Furthermore, the quantity of papers rejected on this criterion supports the existing notion (e.g., Dusseau et al., 2008; Fitzgerald et al., 2008; Turney, 2007) that medical students are not receiving enough anatomy for safe medical practice, especially in fields where anatomy is essential such as surgical fields.

The third exclusion criterion was the most used in discarding papers from the scoping review, where papers were rejected for discussing anatomy without implementing curricular changes. This suggests that a great deal of literature discussed anatomy curricula and changes that should take place without necessarily taking steps to enact those modifications. This relates to the idea that much of the discussion around anatomy and necessary curricular changes is based on anecdotal evidence (Craig et al., 2010; Vorstenbosch et al., 2011).

A total of 195 papers were rejected on exclusion criterion four, where interrelated concepts such as physiology, embryology, etc., were included in the rejected paper. This paper did not examine those articles as a means to assess purely anatomy education, but it is clear that anatomy is closely related to other key sciences, and may be hard to properly teach in isolation of these other fields. This relationship is bidirectional, anatomy depends on a solid understanding of these subjects in order to be fully appreciated. For example, embryological development explains the confusing arrangement of the mediastinum, physiology explains how muscles contract and move joints about their full range of motion, histology explains the microscopic differences between discrete tissue types within the same organ.

## **Novel Classification of Tools for Anatomy Education**

This paper, and the results of the scoping review, were built upon the work of Estai & Bunt (2016). In the process of this review, 33% of the tools used to educate students in anatomy could not be classified according to the nine categories put forth by the authors. Furthermore, the specificity of integrated curricula in anatomy education for medical students is not relevant to other professions requiring anatomy, and was therefore not widely explored in the literature. Finally, three of their nine categories (cadaveric dissection, prosection, and plastination) focus on the use of cadaveric material, and an additional two categories (integrated curricula and system-based curricula) are not mutually exclusive to the use of cadaveric material. When applied beyond purely a medical curriculum, the various teaching methods for anatomy instruction are not captured or well represented. Even within a medical anatomy curriculum, the combination of cadaveric dissection, prosection, and plastination represented only 20% of the available literature included in this scoping review.

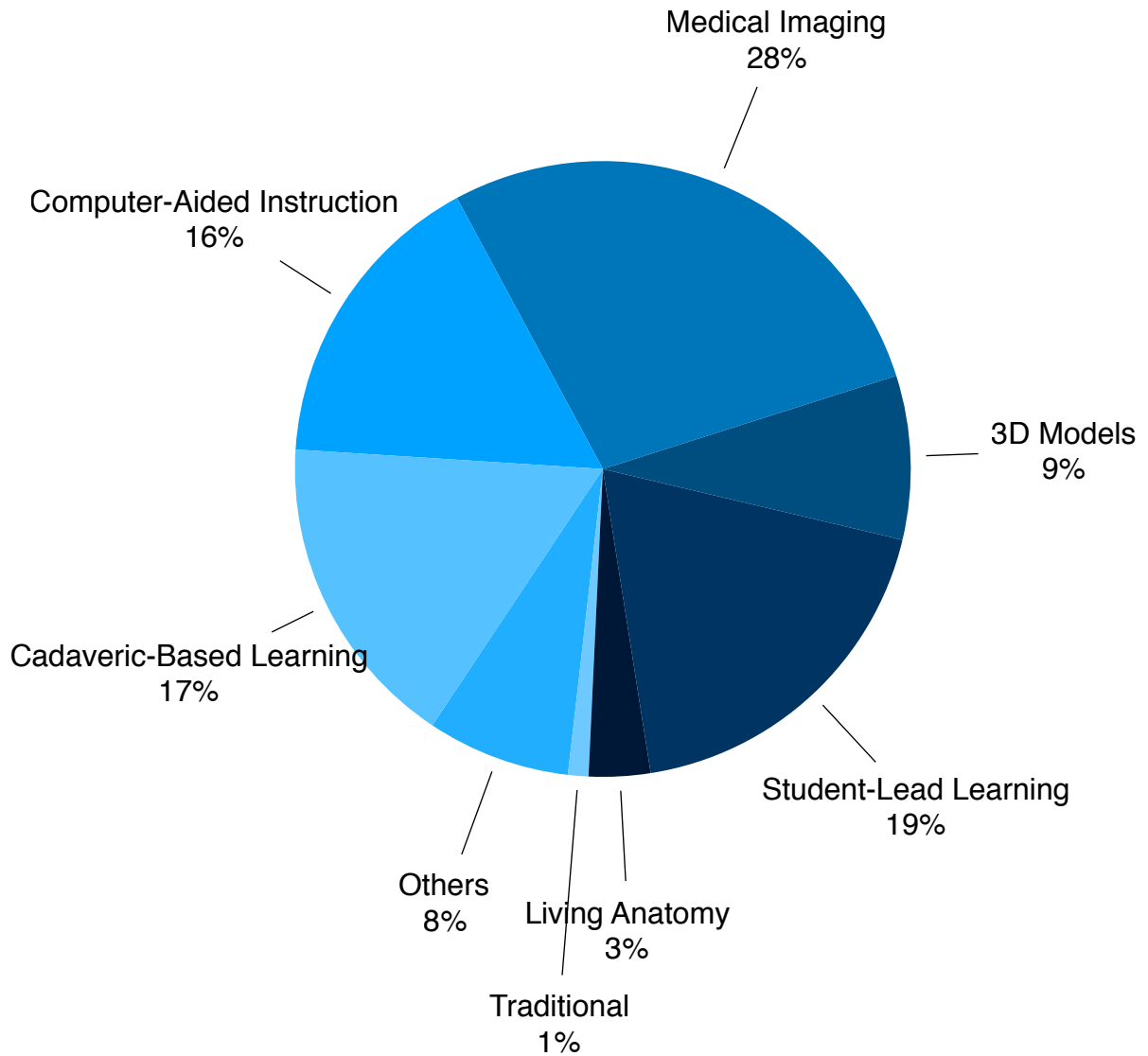
For these reasons, this scoping review puts forward a new framework (Table 4) for outlining the approaches to anatomy instruction that spans multiple disciplines and educational backgrounds. It includes and expands upon the original work of Estai and Bunt (2016) and may be applied to any level or context of anatomy education. Figure 10 shows the distribution of studies across the new categories. However, the re-categorization treats learning tools as individual entities, and does not provide any cl



**Table 3. Classification and Grouping of Anatomy Learning Tools**

<b>Cadaveric - Based Learning</b>	Dissection
	Prosection
	Plastination
	Animal-based dissection
<b>Computer - Aided Learning</b>	Applications and programs
	Augmented reality
	Virtual Reality
	Audiovisual materials
	Audience response systems
	3D computer models
	Mobile device usage
	Electronic textbooks
	Online learning and forums
	<b>Medical Imaging</b>
MRI scans	
X-Rays	
Ultrasound	
Arthroscopy	
3D stereoscopic imaging	
<b>3D Models</b>	Plastic models
	3D printing
	Clay Modeling
<b>Student - Led Learning</b>	Problem - based learning
	Case - based learning
	Team - based learning
	Inquiry - based learning
	Peer teaching and peer tutoring
	Self-directed learning

	Independent study
	Blended learning and flipped classrooms
<b>Living Anatomy</b>	Surface anatomy and palpation
	Body painting
<b>Traditional</b>	Lecture - based learning
	Textbooks
<b>Others</b>	Motor learning
	Games
	Comics
	Art and drawing
	Inter - professional learning
	Craft models
	Youtube, Khan Academy, Kenhub, Coursera
	Physical exercise & activities, body awareness



**Figure 10: Percentage of Categories (Novel Classification)**

The redistribution of studies based on Table 4 is provided here. In general, the distribution between the categories is more balanced. The percentages still reveal the higher proportion of medical imaging and computer-aided instruction compared to cadaveric dissection and other traditional methods.

## **Moving Forward in Anatomy Education: What is Best?**

From the results found throughout the literature, one topical question comes forth: should students in their undergraduate anatomy courses be taught anatomy to the same degree as students in professional programs learning anatomy in the context of patient care? This question has two plausible answers. In cases where students begin their professional training with an undergraduate degree, where they took an anatomy course provides a solid foundation from which to build their anatomical knowledge again in later degrees. It is an upstream approach, attempting to solve the problem before it becomes one. However, not all students will have the luxury of being exposed to an anatomy course in an undergraduate setting if they enter medical school from their high school studies, or if they enter a nursing program where the anatomy encountered in those degrees will serve them for the rest of their respective careers. Furthermore, teaching more anatomy to students in undergraduate degree programs necessitates the allocation of more resources in typically larger class sizes, and knowledge retention tends to be low making it a difficult proposition. It seems clear, then, that the needs of undergraduate students is not the same as those of who are going into patient care careers, and as budget and resources continue, it doesn't seem likely that the undergraduate anatomy class would receive the same level of time, money, and resources as those programs that need it more.

Conversely, some academics ponder if anatomy should be redefined as a postgraduate subject, and taught on a need-to-know basis (Heylings, 2002). The things to learn first in any subject are the fundamentals (Miller, 2000). With this in mind, the question then becomes whether or not anatomy should rearrange itself to become a fundamentals-based course in undergraduate degrees, with field-specific training for students as needed based on their program. This means that only the relevant anatomy is learned to create a foundational understanding of the subject, and resources and time are invested accordingly. This is particularly interesting and relevant to the discussion of anatomy curricula in today's educational climate, where time and resources are continually restricted. This also has the benefit of

exposing students to the content of an anatomy course and overcomes one of the biggest hurdles in anatomy education, learning the fundamentals. While this is a possible solution, it may not provide a satisfactory outcome. This would take a great deal of coordination between programs, faculties, and institutions to ensure consistency between fundamentals courses, and field specific anatomy courses.

Perhaps it is less important to determine which teaching modality is best, but instead focus on capitalizing the utility of each method (Singh & Kharb, 2013). Certain techniques of anatomy education fit certain healthcare professions better than others (Estai & Bunt, 2016). A prime example of this is cadaveric dissection, which is well suited to training future surgeons more than anyone else. It could be considered an exorbitant expenditure of resources to provide undergraduate students with a dissection experience, especially when that undergraduate degree may not lead to patient care where anatomy knowledge is most important. Still, there is no consensus on what amount of anatomical knowledge is required for healthcare practitioners to safely operate in a clinical setting.

Herein lies the answer to the research question; students in different educational programs are taught anatomy differently, and this is unlikely to change. They are different because of different outcomes of differing degree programs, different amounts of resources and budget sizes, and they vary by teaching methods and strategies. This is not necessarily a problem for student learning either. Cadaveric dissection is still employed in some medical schools, and student outcomes in those institutions are not significantly different from other institutions that do not use cadavers to teach their students. The use of medical imaging makes anatomy more clinically relevant and better prepares practitioners for the reality of clinical work. The increasing dependence on computer-based learning and instruction allows teachers to reach ever-larger classes and has been shown to enhance student learning.

## Limitations

The scoping review was limited by the inclusion and exclusion criteria, and therefore it is possible that some studies relevant to the research question were missed when searching databases and other resources. This is compounded by the difficulty in being comprehensive and including all possible literature on the subject at hand. The selection process, by its nature, will miss literature. It was limited to articles published in the last ten years, and only those articles published in English. Clearly, there are relevant articles published before the arbitrary timeframe and relevant scholarship written in other languages that would have contributed to addressing the research question. More databases might have yielded a greater number of papers to help answer the research question.

Furthermore, there was only one reviewer responsible for the process of selecting articles. It is common practice for a scoping review to utilize teams of researchers to complete the review process, providing redundancy and more validity to the results. Because only one author was responsible for this work, the reliability of the findings or replicability of the results may be limited by the bias or fallibility of the author.

Due to limitations in duration and rigour of a scoping review, there is a potential for bias within the findings of the review (Grant & Booth, 2009). A review examining literature over a longer timeframe, or the additional rigour offered by a systematic review would reduce this effect.

Finally, there was no assessment of the quality of the studies used in this scoping review. It is possible, therefore, for studies to be included by virtue of existence, rather than by virtue of quality (Grant & Booth, 2009). It is important to note that assessing the quality of the articles included in the analysis was beyond the scope of this review. While care was taken to ensure that included articles were of sufficient quality, there was no formalized process for assessing the articles included.

## **Future Directions**

In the last quarter century, a broad range of teaching resources have emerged to augment theoretical and practical classes (Vázquez et al., 2007). Ahmed and colleagues (2010) claim that future research in the area of anatomy education should focus on development and validation of new teaching tools. Anatomy educators should feel empowered to continue experimenting with new teaching techniques (Wilson et al., 2019). There should be no reason not to include new and exciting technological advancements (Ma et al., 2016).

This paper did not take the perspective of the student learner or the teacher when assessing the literature. Instead, the paper examined the nature of student education as a process between the teacher and the student. Students must be included in discussions of curricula changes (Aversi-Ferreira et al., 2010). A different understanding of the research question may have arisen if student perceptions of anatomy education was incorporated into the research question or the database search terms. It would be important to consider student opinions and perceptions going forward, regardless of the educational context in which students are taking an anatomy course. Some studies have captured this by examining student comfort with their level of anatomy education (e.g., Fitzgerald et al., 2008; Mitchell & Batty, 2009), but these studies look at the result of an existing anatomy course and often do not gather student perspectives for the purposes of shaping the curricula or selecting appropriate educational interventions or strategies. Furthermore, gathering student opinion is important to help determine if the recent changes in anatomy education are meeting the needs of students, and where more work can be directed to make anatomy courses a meaningful learning experience. In this case, student opinion can serve as a barometer to measure the outcomes of modified anatomy curricula and interventions beyond gathering examination results.

Another key area of research should focus on expanding the learner population. Many papers were rejected from this study because they focused on doctors in their residency training, surgery-specific training, and so forth. These are important

populations of students and professionals where anatomy is important but they were restricted from this scoping review so as to focus in on students themselves.

Another important consideration is the effect of these learning tools on long term retention of anatomy content. Many studies examined only short term impacts of their respective pedagogies. More work is needed to understand how changes in anatomy instruction leads to long term changes in preparing students for clinical work (Wilson et al., 2019). Learning anatomy is analogous to learning to read (Miller, 2000) and while it may be a challenging subject for students to learn, it is a vital component of the training of future healthcare professionals (Ma et al., 2016).

Similarly, further studies could utilize the learning tools and categories identified in Table 4 to gain further insight into the nature of anatomy education. For example, course syllabi could be gathered and analyzed for teaching methods and tools implemented in anatomy curricula. A study could also create and distribute a survey to institutions that teach anatomy to the identified student populations. The results from this type of survey could be compared to the data generated in this scoping review to help validate the results.

Grant & Booth (2009) demonstrate that a weakness of the scoping review lies in its inability to recommend policy or practice. In that regard, this paper serves to summarize the literature pertaining to different educational requirements for the field of anatomy to different student populations. Therefore, a future direction for this research would be to conduct a systematic review to determine if changes to the anatomy curriculum is required. This systematic review could remove the bias created by not assessing the quality of articles before being included in the review, and could provide a better understanding into the process of changing the anatomy curricula to better suit the needs to students.



## Conclusion

The purpose of this scoping review was to gain a better understanding of the current state of anatomy education across multiple student disciplines. Anatomy is an interesting domain of education. Its unique nature, including the specific language and terminology, three-dimensional structure, and the direct impact it has on patient care, makes it a difficult subject for experts to teach and students to master. Moreover, it is an important subject because of the close links it shares with safe patient care in clinical and therapeutic settings. It is a subject that is important to multiple disciplines within the domain of healthcare. In this scoping review, students across medical, dental, rehabilitation, nursing, and undergraduate populations were examined to assess the different approaches and techniques to teaching anatomy.

As professional education and expectations change, so do the needs of the students and their own preferences when it comes to their education. This scoping review demonstrated the increasing student interest in CAI, which should not be a surprise given the ubiquitous use of electronic devices in classrooms and daily life. It also demonstrated the increased use and implementation of medical imaging within the classroom setting, which is well-matched to the increased reliance on medical imaging in the clinical setting for diagnosing and treating patients.

Irrespective of the purpose for which students are learning anatomy, course content is complex and can be challenging for learners (Wang et al., 2010). There is no absolute zenith or perfect solution for anatomy education (Smith & Mathias, 2011; Wilhelmsson et al., 2010). However, this fact has not stopped educators from trying to bridge the gap between curiosity and knowledge for their students, and underscores the important impact that teaching strategies can have on anatomy education for all sorts of learners.

New teaching strategies and modalities continue to develop and mature and will therefore continue to receive attention in the literature and positively affect student

learning where implemented. As these new technologies are being integrated in the classroom, the value of more traditional methods should not be dismissed. Cadaveric dissection, which has great historical significance in anatomy training, does not lose merit simply because new pedagogies are being used. Rather, it becomes a more niche form of anatomy training, reserved for those who need it for their training. Furthermore, the use of these technologies can augment the utility of older methods, for example, using medical imaging to complement cadaveric dissection, making lectures more interactive, or using digital textbooks to increase student uptake.

It is encouraging to see an increase in the body of literature surrounding anatomy education, and perhaps the increased awareness and attention can positively address the critical relationship between anatomical training and safe patient care.

## References

- Abed Rabbo, F., Garrigues, F., Lefevre, C., & Seizeur, R. (2016). Interactive anatomical teaching: Integrating radiological anatomy within topographic anatomy. *Morphologie*, 100(328), 17-23. doi:10.1016/j.morpho.2015.08.004
- Agius, A., Calleja, N., Camenzuli, C., Sultana, R., Pullicino, R., Zammit, C., . . . Pomara, C. (2018). Perceptions of first-year medical students towards learning anatomy using cadaveric specimens through peer teaching. *Anat Sci Educ*, 11(4), 346-357. doi:10.1002/ase.1751
- Agius, A., & Stabile, I. (2018). Undergraduate peer assisted learning tutors' performance in summative anatomy examinations: a pilot study. *Int J Med Educ*, 9, 93-98. doi:10.5116/ijme.5aa3.e2a6
- Ahmad, M., Sleiman, N. H., Thomas, M., Kashani, N., & Ditmyer, M. M. (2016). Use of High-Definition Audiovisual Technology in a Gross Anatomy Laboratory: Effect on Dental Students' Learning Outcomes and Satisfaction. *J Dent Educ*, 80(2), 128-132.
- Ahmed, K., Rowland, S., Patel, V., Khan, R. S., Ashrafian, H., Davies, D. C., . . . Paraskeva, P. A. (2010). Is the structure of anatomy curriculum adequate for safe medical practice? *Surgeon, The*, 8(6), 318-324. doi:10.1016/j.surge.2010.06.005
- Al-Madi, E. M., Celur, S. L., & Nasim, M. (2018). Effectiveness of PBL methodology in a hybrid dentistry program to enhance students' knowledge and confidence. (a pilot study). *BMC Med Educ*, 18(1), 270. doi:10.1186/s12909-018-1392-y
- Alfalah, S. F. M., Falah, J. F. M., Alfalah, T., Elfalah, M., Muhaidat, N., & Falah, O. (2018). A comparative study between a virtual reality heart anatomy system

and traditional medical teaching modalities. *Virtual Reality*. doi:10.1007/s10055-018-0359-y

- Alsaid, B., & Bertrand, M. (2016). Students' memorization of anatomy, influence of drawing. *Morphologie*, 100(328), 2-6. doi:10.1016/j.morpho.2015.11.001
- Ang, E. T., Chan, J. M., Gopal, V., & Li Shia, N. (2018). Gamifying anatomy education. *Clin Anat*, 31(7), 997-1005. doi:10.1002/ca.23249
- Anstey, L. M. (2017). "Applying Anatomy to Something I Care About": Authentic Inquiry Learning and Student Experiences of an Inquiry Project. *Anat Sci Educ*, 10(6), 538-548. doi:http://dx.doi.org/10.1002/ase.1690
- Anstey, L. M., Michels, A., Szymus, J., Law, W., Edwin Ho, M. H., Qu, F., . . . Chow, N. (2014). Reflections as near-peer facilitators of an inquiry project for undergraduate anatomy: Successes and challenges from a term of trial-and-error. *Anat Sci Educ*, 7(1), 64-70. doi:10.1002/ase.1383
- Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, 8(1), 19-32. doi:10.1080/1364557032000119616
- Arslan, O. E. (2014). Region vs. system-based anatomy: efficacy and implementation. *Am. Int. J. Biol*, 2(3), 01-23.
- Arya, R., Morrison, T., Zumwalt, A., & Shaffer, K. (2013). Making education effective and fun: stations-based approach to teaching radiology and anatomy to third-year medical students. *Acad Radiol*, 20(10), 1311-1318. doi:10.1016/j.acra.2013.07.012

- Attardi, S. M., Choi, S., Barnett, J., & Rogers, K. A. (2016). Mixed methods student evaluation of an online systemic human anatomy course with laboratory. *Anat Sci Educ*, 9(3), 272-285. doi:10.1002/ase.1584
- Aversi-Ferreira, T. A., do Nascimento, G. N. L., Vera, I., & Lucchese, R. (2010). The practice of dissection as teaching methodology in anatomy applied to medical education. *International Journal of Morphology*, 28(1), 265-272. doi: 10.4067/S0717-95022010000100039
- Azer, S. A., & Eizenberg, N. (2007). Do we need dissection in an integrated problem-based learning medical course? Perceptions of first- and second-year students. *Surgical and Radiologic Anatomy*, 29(2), 173-180. doi:10.1007/s00276-007-0180-x
- Aziz, M. A., McKenzie, J. C., Wilson, J. S., Cowie, R. J., Ayeni, S. A., & Dunn, B. K. (2002). The human cadaver in the age of biomedical informatics. *The Anatomical Record*, 269(1), 20-32. doi:10.1002/ar.10046
- Baker, E. W., Slott, P. A., Terracio, L., & Cunningham, E. P. (2013). An innovative method for teaching anatomy in the predoctoral dental curriculum. *J Dent Educ*, 77(11), 1498-1507.
- Bareither, M. L., Arbel, V., Growe, M., Muszczynski, E., Rudd, A., & Marone, J. R. (2013). Clay Modeling versus Written Modules as Effective Interventions in Understanding Human Anatomy. *Anat Sci Educ*, 6(3), 170-176. doi:http://dx.doi.org/10.1002/ase.1321
- Barton, C. E., Williams, C. L., Halle, J. S., & McGrew, L. (2018). Graduate and Undergraduate Faculty Collaboration Utilizing Peer Observation to Enhance Educational Opportunities for Students and Faculty: A Case Example. *Journal of the Scholarship of Teaching and Learning*, 18(3), 189-211.

- Battulga, B., Konishi, T., Tamura, Y., & Moriguchi, H. (2012). The effectiveness of an interactive 3-dimensional computer graphics model for medical education. *Interact J Med Res*, 1(2), e2. doi:10.2196/ijmr.2172
- Bell, L. T., & Evans, D. J. (2014). Art, anatomy, and medicine: Is there a place for art in medical education? *Anat Sci Educ*, 7(5), 370-378. doi:10.1002/ase.1435
- Bergman, E. M. (2015). Discussing dissection in anatomy education. *Perspect Med Educ*, 4(5), 211-213. doi:10.1007/s40037-015-0207-7
- Bergman, E. M., de Bruin, A. B., Herrler, A., Verheijen, I. W., Scherpbier, A. J., & van der Vleuten, C. P. (2013). Students' perceptions of anatomy across the undergraduate problem-based learning medical curriculum: a phenomenographical study. *BMC Med Educ*, 13, 152. doi:10.1186/1472-6920-13-152
- Berney, S., Bétrancourt, M., Molinari, G., & Hoyek, N. (2015). How Spatial Abilities and Dynamic Visualizations Interplay When Learning Functional Anatomy with 3D Anatomical Models. *Anat Sci Educ*, 8(5), 452-462. doi:http://dx.doi.org/10.1002/ase.1524
- Bohl, M., Francois, W., & Gest, T. (2011). Self-guided clinical cases for medical students based on postmortem CT scans of cadavers. *Clin Anat*, 24(5), 655-663. doi:10.1002/ca.21143
- Bork, F., Stratmann, L., Enssle, S., Eck, U., Navab, N., Waschke, J., & Kugelmann, D. (2019). The Benefits of an Augmented Reality Magic Mirror System for Integrated Radiology Teaching in Gross Anatomy. *Anat Sci Educ*. doi:10.1002/ase.1864
- Brooks, W. S., Woodley, K. T. C. P., Jackson, J. R., & Hoesley, C. J. (2015). Integration of gross anatomy in an organ system-based medical curriculum:

Strategies and challenges. *Anat Sci Educ*, 8(3), 266-274. doi:10.1002/ase.1483

Brown, B., Adhikari, S., Marx, J., Lander, L., & Todd, G. L. (2012a). Introduction of ultrasound into gross anatomy curriculum: perceptions of medical students. *J Emerg Med*, 43(6), 1098-1102. doi:10.1016/j.jemermed.2012.01.041

Brown, P. M., Hamilton, N. M., & Denison, A. R. (2012b). A novel 3D stereoscopic anatomy tutorial. *Clin Teach*, 9(1), 50-53. doi:10.1111/j.1743-498X.2011.00488.x

Bruno, P. A., Love Green, J. K., Illerbrun, S. L., Holness, D. A., Illerbrun, S. J., Haus, K. A., . . . Sveinson, K. L. (2016). Students helping students: Evaluating a pilot program of peer teaching for an undergraduate course in human anatomy. *Anat Sci Educ*, 9(2), 132-142. doi:10.1002/ase.1543

Buenting, M., Mueller, T., Raupach, T., Luers, G., Wehrenberg, U., Gehl, A., & Anders, S. (2016). Post mortem CT scans as a supplementary teaching method in gross anatomy. *Ann Anat*, 208, 165-169. doi:10.1016/j.aanat.2016.05.003

Burgess, A., & Ramsey-Stewart, G. (2015). Anatomy by whole body dissection: a focus group study of students' learning experience. *Adv Med Educ Pract*, 6, 533-537. doi:10.2147/amep.S86583

Cai, B., Rajendran, K., Bay, B. H., Lee, J., & Yen, C. C. (2018). The Effects of a Functional Three-dimensional (3D) Printed Knee Joint Simulator in Improving Anatomical Spatial Knowledge. *Anat Sci Educ*. doi:10.1002/ase.1847

Calkins, C. M., Franciosi, J. P., & Kolesari, G. L. (1999). Human anatomical science and illustration: The origin of two inseparable disciplines. *Clinical Anatomy*,

12(2), 120-129. doi:10.1002/(SICI)1098-2353(1999)12:2<120::AID-CA7>3.0.CO;2-V

Canty, D. J., Hayes, J. A., Story, D. A., & Royse, C. F. (2015). Ultrasound simulator-assisted teaching of cardiac anatomy to preclinical anatomy students: A pilot randomized trial of a three-hour learning exposure. *Anat Sci Educ*, 8(1), 21-30. doi:10.1002/ase.1452

Carter, J. L., Hocum, G., Pellicer, R., Patel, A., & Benninger, B. (2016). Integration of 3D/4D Ultrasound in Teaching Medical Anatomy. *Med Sci Educ*, 26(3), 343-348. doi:10.1007/s40670-016-0271-6

Carter, J. L., Patel, A., Hocum, G., & Benninger, B. (2017). Thyroid gland visualization with 3D/4D ultrasound: integrated hands-on imaging in anatomical dissection laboratory. *Surg Radiol Anat*, 39(5), 567-572. doi:10.1007/s00276-016-1775-x

Chen, S., Pan, Z., Wu, Y., Gu, Z., Li, M., Liang, Z., . . . Pan, H. (2017). The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trial. *Sci Rep*, 7(1), 575. doi:10.1038/s41598-017-00647-1

Choi-Lundberg, D. L., Cuellar, W. A., & Williams, A.-M. M. (2016). Online Dissection Audio-Visual Resources for Human Anatomy: Undergraduate Medical Students' Usage and Learning Outcomes. *Anat Sci Educ*, 9(6), 545-554. doi:http://dx.doi.org/10.1002/ase.1607

Christensen, J. D., Schmalz, N. A., Challyandra, L., & Stark, M. E. (2018). Establishment of a Peer Teaching Assistant Program for Preclinical Human Gross Anatomy Curricula. *Med Sci Educ*, 28(4), 765-772. doi:10.1007/s40670-018-0604-8



- Codd, A. M., & Choudhury, B. (2011). Virtual Reality Anatomy: Is It Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy? *Anat Sci Educ*, 4(3), 119-125. doi:<http://dx.doi.org/10.1002/ase.214>
- Craig, S., Tait, N., Boers, D., & McAndrew, D. (2010). Review of anatomy education in Australian and New Zealand medical schools. *ANZ J Surg*, 80(4), 212-216. doi:10.1111/j.1445-2197.2010.05241.x
- Cuddy, M. M., Swanson, D. B., Drake, R. L., & Pawlina, W. (2013). Changes in anatomy instruction and USMLE performance: Empirical evidence on the absence of a relationship. *Anat Sci Educ*, 6(1), 3-10. doi:10.1002/ase.1343
- Cui, D., Wilson, T. D., Rockhold, R. W., Lehman, M. N., & Lynch, J. C. (2017). Evaluation of the effectiveness of 3D vascular stereoscopic models in anatomy instruction for first year medical students. *Anat Sci Educ*, 10(1), 34-45. doi:10.1002/ase.1626
- Dangerfield, P., Bradley, P., & Gibbs, T. (2000). Learning gross anatomy in a clinical skills course. *Clinical Anatomy*, 13(6), 444-447. doi:10.1002/1098-2353(2000)13:6<444::AID-CA9>3.0.CO;2-W
- Dettmer, S., Schmiedl, A., Meyer, S., Giesemann, A., Pabst, R., Weidemann, J., . . . Kirchhoff, T. (2013). Radiological anatomy - evaluation of integrative education in radiology. *Rofo*, 185(9), 838-843. doi:10.1055/s-0033-1335048
- Dickman, N., Barash, A., Reis, S., & Karasik, D. (2017). Students as anatomy near-peer teachers: a double-edged sword for an ancient skill. *BMC Med Educ*, 17(1), 156. doi:10.1186/s12909-017-0996-y

- Dinsmore, C. E., Paul, H. A., & Sweet, F. A. (1993). A Course of study in the anatomical sciences for a problem-based curriculum. *Clinical Anatomy*, 6(4), 240-246. doi:10.1002/ca.980060408
- Drake, R. L., McBride, J. M., Lachman, N., & Pawlina, W. (2009). Medical education in the anatomical sciences: the winds of change continue to blow. *Anat Sci Educ*, 2(6), 253-259. doi:10.1002/ase.117
- Duran, C. E. P., Bahena, E. N., Rodriguez, M. d. I. A. G., Baca, G. J., Uresti, A. S., Elizondo-Omana, R. E., & Lopez, S. G. (2012). Near-Peer Teaching in an Anatomy Course with a Low Faculty-to-Student Ratio. *Anat Sci Educ*, 5(3), 171-176. doi:http://dx.doi.org/10.1002/ase.1269
- Durosaro, O., Lachman, N., & Pawlina, W. (2008). Use of knowledge-sharing web-based portal in gross and microscopic anatomy. *Annals Academy of Medicine Singapore*, 37(12), 998.
- Dusseau, J., Knutson, D., & Way, D. (2008). Anatomy correlations: introducing clinical skills to improve performance in anatomy. *Family medicine*, 40(9), 633-637.
- Elizondo-Omaña, R. E., Guzmán-López, S., & García-Rodríguez, M. D. L. A. (2005). Dissection as a teaching tool: past, present, and future. *Anatomical record. Part B, New anatomist*, 285(1), 11-15. doi:10.1002/ar.b.20070
- Estai, M., & Bunt, S. (2016). Best teaching practices in anatomy education: A critical review. *Annals of Anatomy*, 208, 151-157. doi:10.1016/j.aanat.2016.02.010
- Evans, D. J. R., & Watt, D. J. (2005). Provision of anatomical teaching in a new British medical school: getting the right mix. *Anatomical record. Part B, New anatomist*, 284(1), 22-27. doi:10.1002/ar.b.20065

- Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., García, S., & Barcia, J. M. (2015). ARBOOK: Development and Assessment of a Tool Based on Augmented Reality for Anatomy. *Journal of Science Education and Technology*, 24(1), 119-124. doi:<http://dx.doi.org/10.1007/s10956-014-9526-4>
- Findlater, G. S., Kristmundsdottir, F., Parson, S. H., & Gillingwater, T. H. (2012). Development of a supported self-directed learning approach for anatomy education. *Anat Sci Educ*, 5(2), 114-121. doi:10.1002/ase.1255
- Finn, G. M., & McLachlan, J. C. (2010). A Qualitative Study of Student Responses to Body Painting. *Anat Sci Educ*, 3(1), 33-38.
- Finn, G. M., White, P. M., & Abdelbagi, P. M. (2011). The Impact of Color and Role on Retention of Knowledge: A Body-Painting Study within Undergraduate Medicine. *Anat Sci Educ*, 4(6), 311-317. doi:<http://dx.doi.org/10.1002/ase.253>
- Fitzgerald, J. E. F., White, M. J., Tang, S. W., Maxwell-Armstrong, C. A., & James, D. K. (2008). Are we teaching sufficient anatomy at medical school? The opinions of newly qualified doctors. *Clinical Anatomy*, 21(7), 718-724. doi:10.1002/ca.20662
- Fleagle, T. R., Borchering, N. C., Harris, J., & Hoffmann, D. S. (2018). Application of Flipped Classroom Pedagogy to the Human Gross Anatomy Laboratory: Student Preferences and Learning Outcomes. *Anat Sci Educ*, 11(4), 385-396. doi:<http://dx.doi.org/10.1002/ase.1755>
- Fritz, D., Hu, A., Wilson, T., Ladak, H., Haase, P., & Fung, K. (2011). Long-term retention of a 3-dimensional educational computer model of the larynx: a follow-up study. *Arch Otolaryngol Head Neck Surg*, 137(6), 598-603. doi:10.1001/archoto.2011.76

- Ghorbani, N., Karbalay-Doust, S., & Noorafshan, A. (2014). Is a Team-based Learning Approach to Anatomy Teaching Superior to Didactic Lecturing? *Sultan Qaboos Univ Med J*, 14(1), e120-125.
- Gillingwater, T. H. (2008). The importance of exposure to human material in anatomical education: A philosophical perspective. *Anat Sci Educ*, 1(6), 264-266. doi:10.1002/ase.52
- Graham, C. R. (2006). Blended learning systems. *The handbook of blended learning*, 3-21.
- Granger, N. A. (2004). Dissection laboratory is vital to medical gross anatomy education. *The Anatomical Record Part B: The New Anatomist*, 281B(1), 6-8. doi:10.1002/ar.b.20039
- Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), 91-108. doi:10.1111/j.1471-1842.2009.00848.x
- Green, R. A., Farchione, D., Hughes, D. L., & Chan, S. P. (2014). Participation in asynchronous online discussion forums does improve student learning of gross anatomy. *Anat Sci Educ*, 7(1), 71-76. doi:10.1002/ase.1376
- Green, R. A., & Hughes, D. L. (2013). Student Outcomes Associated with Use of Asynchronous Online Discussion Forums in Gross Anatomy Teaching. *Anat Sci Educ*, 6(2), 101-106. doi:http://dx.doi.org/10.1002/ase.1310
- Green, R. A., & Whitburn, L. Y. (2016). Impact of introduction of blended learning in gross anatomy on student outcomes. *Anat Sci Educ*, 9(5), 422-430. doi:10.1002/ase.1602

- Greene, S. J. (2018). The Use and Effectiveness of Interactive Progressive Drawing in Anatomy Education. *Anat Sci Educ*, 11(5), 445-460. doi:<http://dx.doi.org/10.1002/ase.1784>
- Griksaitis, M. J., Sawdon, M. A., & Finn, G. M. (2012). Ultrasound and Cadaveric Prosections as Methods for Teaching Cardiac Anatomy: A Comparative Study. *Anat Sci Educ*, 5(1), 20-26. doi:<http://dx.doi.org/10.1002/ase.259>
- Gunderman, R. B., & Wilson, P. K. (2005). Viewpoint: exploring the human interior: the roles of cadaver dissection and radiologic imaging in teaching anatomy. *Acad Med*, 80(8), 745-749.
- Hadie, S. N. H., Hassan, A., Ismail, Z. I. M., Asari, M. A., Khan, A. A., Kasim, F., . . . Yusoff, M. S. B. (2017). Anatomy education environment measurement inventory: A valid tool to measure the anatomy learning environment: Anatomy Learning Environment Measurement Tool. *Anat Sci Educ*, 10(5), 423-432. doi:10.1002/ase.1683
- Hall, S., Lewis, M., Border, S., & Powell, M. (2013). Near-peer teaching in clinical neuroanatomy. *Clin Teach*, 10(4), 230-235.
- Hanna, C. (2014). Tournaments, rankings, and the time crunches: exploring the use of competition technologies in the classroom. School of Graduate and Postdoctoral Studies, University of Western Ontario
- Hanna, C., Johnson, A. M., & Belliveau, D. J. (2015). Fostering Student Motivation through Competition: How Competing in Online Tournaments in Teams Affects the Performance Related Outcomes of Participants. *Ubiquitous Learning: An International Journal*, 7(3-4), 19-40. doi:<https://doi.org/10.18848/1835-9795/CGP/v07i3-4/40411>

- Herrmann, G., Woermann, U., & Schlegel, C. (2015). Interprofessional education in anatomy: Learning together in medical and nursing training. *Anat Sci Educ*, 8(4), 324-330. doi:10.1002/ase.1506
- Heylings, D. J. A. (2002). Anatomy 1999–2000: the curriculum, who teaches it and how? *Med Educ*, 36(8), 702-710. doi:10.1046/j.1365-2923.2002.01272.x
- Hill, R. V., & Nassrallah, Z. (2018). A Game-Based Approach to Teaching and Learning Anatomy of the Liver and Portal Venous System. *MedEdPORTAL*, 14, 10696. doi:10.15766/mep\_2374-8265.10696
- Holland, J. C., & Pawlikowska, T. (2018). Undergraduate Medical Students' Usage and Perceptions of Anatomical Case-Based Learning: Comparison of Facilitated Small Group Discussions and eLearning Resources. *Anat Sci Educ*. doi:10.1002/ase.1824
- Horneffer, A., Fassnacht, U., Oechsner, W., Huber-Lang, M., Boeckers, T. M., & Boeckers, A. (2016). Effect of didactically qualified student tutors on their tutees' academic performance and tutor evaluation in the gross anatomy course. *Ann Anat*, 208, 170-178. doi:10.1016/j.aanat.2016.05.008
- Howe, A., Champion, P., Searle, J., & Smith, H. (2004). New perspectives—approaches to medical education at four new UK medical schools. *BMJ*, 329(7461), 327-331. doi:10.1136/bmj.329.7461.327
- Hoyek, N., Collet, C., Di Rienzo, F., De Almeida, M., & Guillot, A. (2014). Effectiveness of three-dimensional digital animation in teaching human anatomy in an authentic classroom context. *Anat Sci Educ*, 7(6), 430-437. doi:10.1002/ase.1446

- Inuwa, I. M. (2012). Perceptions and Attitudes of First-Year Medical Students on a Modified Team-Based Learning (TBL) Strategy in Anatomy. *Sultan Qaboos Univ Med J*, 12(3), 336-343.
- Ivanusic, J., Cowie, B., & Barrington, M. (2010). Undergraduate Student Perceptions of the Use of Ultrasonography in the Study of "Living Anatomy". *Anat Sci Educ*, 3(6), 318-322. doi:<http://dx.doi.org/10.1002/ase.180>
- Jaffar, A. A. (2012). YouTube: An emerging tool in anatomy education. *Anat Sci Educ*, 5(3), 158-164. doi:10.1002/ase.1268
- James, H. K., Chapman, A. W. P., Dhukaram, V., Wellings, R., & Abrahams, P. (2018). Learning anatomy of the foot and ankle using sagittal plastinates: A prospective randomized educational trial. *Foot (Edinb)*, 38, 34-38. doi:10.1016/j.foot.2018.11.004
- Janssen, A., Shaw, T., Goodyear, P., Kerfoot, B. P., & Bryce, D. (2015). A little healthy competition: using mixed methods to pilot a team-based digital game for boosting medical student engagement with anatomy and histology content. *BMC Med Educ*, 15, 173. doi:10.1186/s12909-015-0455-6
- Jariyapong, P., Punsawad, C., Bunratsami, S., & Kongthong, P. (2016). Body painting to promote self-active learning of hand anatomy for preclinical medical students. *Med Educ Online*, 21, 30833. doi:10.3402/meo.v21.30833
- Jarral, S. A., Mehboob, F., & Ashraf, S. (2017). Students' response on the effectiveness of CBL in learning Gross anatomy in an undergraduate course. *Pakistan Journal of Medical and Health Sciences*, 11(3), 917-921.
- Johnson, E. O., Charchanti, A. V., & Troupis, T. G. (2012). Modernization of an anatomy class: From conceptualization to implementation. A case for

integrated multimodal-multidisciplinary teaching. *Anat Sci Educ*, 5(6), 354-366. doi:10.1002/ase.1296

Jurjus, R. A., Dimorier, K., Brown, K., Slaby, F., Shokoohi, H., Boniface, K., & Liu, Y. T. (2014). Can anatomists teach living anatomy using ultrasound as a teaching tool? *Anat Sci Educ*, 7(5), 340-349. doi:10.1002/ase.1417

Keedy, A. W., Durack, J. C., Sandhu, P., Chen, E. M., O'Sullivan, P. S., & Breiman, R. S. (2011). Comparison of Traditional Methods with 3D Computer Models in the Instruction of Hepatobiliary Anatomy. *Anat Sci Educ*, 4(2), 84-91. doi:http://dx.doi.org/10.1002/ase.212

Kelly, D., Hoang, T. N., Reinoso, M., Joukhadar, Z., Clements, T., & Vetere, F. (2018). Augmented reality learning environment for physiotherapy education. *Physical Therapy Reviews*, 23(1), 21-28. doi:10.1080/10833196.2018.1447256

Kerby, J., Shukur, Z. N., & Shalhoub, J. (2011). The relationships between learning outcomes and methods of teaching anatomy as perceived by medical students. *Clinical Anatomy*, 24(4), 489-497. doi:10.1002/ca.21059

Kharb, P., & Samanta, P. P. (2016). Blended learning approach for teaching and learning anatomy: Students' and teachers' perspective. *Journal of the Anatomical Society of India*, 65(1), 43-47. doi:10.1016/j.jasi.2016.06.001

Khot, Z., Quinlan, K., Norman, G. R., & Wainman, B. (2013). The relative effectiveness of computer-based and traditional resources for education in anatomy. *Anat Sci Educ*, 6(4), 211-215. doi:10.1002/ase.1355

Kinirons, S. A., Reddin, V. M., & Maguffin, J. (2018). Effects of Alternating Dissection with Peer Teaching and Faculty Prosected Cadaver Demonstrations in a



Physical Therapy and Occupational Therapy Gross Anatomy Course. *Anat Sci Educ*. doi:10.1002/ase.1833

- Knobe, M., Carow, J. B., Ruessler, M., Leu, B. M., Simon, M., Beckers, S. K., . . . Pape, H. C. (2012). Arthroscopy or ultrasound in undergraduate anatomy education: a randomized cross-over controlled trial. *BMC Med Educ*, *12*, 85. doi:10.1186/1472-6920-12-85
- Kolossvary, M., Szekely, A. D., Gerber, G., Merkely, B., & Maurovich-Horvat, P. (2017). CT Images Are Noninferior to Anatomic Specimens in Teaching Cardiac Anatomy-A Randomized Quantitative Study. *J Am Coll Radiol*, *14*(3), 409-415.e402. doi:10.1016/j.jacr.2016.09.050
- Kondrashova, T., De Wan, D., Briones, M. U., & Kondrashov, P. (2017). Integration of ultrasound imaging into pre-clinical dental education. *Eur J Dent Educ*, *21*(4), 228-234. doi:10.1111/eje.12205
- Kong, X., Nie, L., Zhang, H., Wang, Z., Ye, Q., Tang, L., . . . Huang, W. (2016). Do Three-dimensional Visualization and Three-dimensional Printing Improve Hepatic Segment Anatomy Teaching? A Randomized Controlled Study. *J Surg Educ*, *73*(2), 264-269. doi:10.1016/j.jsurg.2015.10.002
- Kooloos, J. G., Schepens-Franke, A. N., Bergman, E. M., Donders, R. A., & Vorstenbosch, M. A. (2014). Anatomical knowledge gain through a clay-modeling exercise compared to live and video observations. *Anat Sci Educ*, *7*(6), 420-429. doi:10.1002/ase.1443
- Kotzé, S. H., Mole, C. G., & Greyling, L. M. (2012). The translucent cadaver: an evaluation of the use of full body digital X-ray images and drawings in surface anatomy education. *Anat Sci Educ*, *5*(5), 287-294.

- Kugelmann, D., Stratmann, L., Nuhlen, N., Bork, F., Hoffmann, S., Samarbarksh, G., . . . Waschke, J. (2018). An Augmented Reality magic mirror as additive teaching device for gross anatomy. *Ann Anat*, *215*, 71-77. doi:10.1016/j.aanat.2017.09.011
- Larkin, T. A., & McAndrew, D. J. (2013). Factors influencing students' decisions to participate in a short "dissection experience" within a systemic anatomy course. *Anat Sci Educ*, *6*(4), 225-231. doi:10.1002/ase.1323
- Latorre, R. M., García-Sanz, M. P., Moreno, M., Hernández, F., Gil, F., López, O., . . . Arencibia, A. (2007). How useful is plastination in learning anatomy? *J Vet Med Educ*, *34*(2), 172-176.
- Lazarus, L., Sookrajh, R., & Satyapal, K. S. (2017). Tablet technology in medical education in South Africa: a mixed methods study. *BMJ Open*, *7*(7), e013871. doi:10.1136/bmjopen-2016-013871
- Lee, V. S. (2004). *Teaching and learning through inquiry: a guidebook for institutions and instructors* (1st ed.). Sterling, Va: Stylus Pub
- Leung, K.-k., Lu, K.-S., Huang, T.-S., & Hsieh, B.-S. (2006). Anatomy Instruction in Medical Schools: Connecting the Past and the Future. *Advances in Health Sciences Education*, *11*(2), 209-215. doi:10.1007/s10459-005-1256-1
- Lewis, T. L., Sagmeister, M. L., Miller, G. W., Boissaud-Cooke, M. A., & Abrahams, P. H. (2016). Anatomy, radiology, and practical procedure education for foundation doctors in England: A National Observational Study. *Clin Anat*, *29*(8), 982-990. doi:10.1002/ca.22783
- Li, Z., Li, Z., Xu, R., Li, M., Li, J., Liu, Y., . . . Chen, Z. (2015). Three-dimensional printing models improve understanding of spinal fracture-A randomized controlled study in China. *Sci Rep*, *5*. doi:10.1038/srep11570

- Lim, K. H. A., Loo, Z. Y., Goldie, S. J., Adams, J. W., & McMenemy, P. G. (2016). Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. *Anat Sci Educ*, 9(3), 213-221. doi:10.1002/ase.1573
- Lufler, R. S., Zumwalt, A. C., Romney, C. A., & Hoagland, T. M. (2010). Incorporating Radiology into Medical Gross Anatomy: Does the Use of Cadaver CT Scans Improve Students' Academic Performance in Anatomy? *Anat Sci Educ*, 3(2), 56-63.
- Ma, M., Fallavollita, P., Seelbach, I., Von Der Heide, A. M., Euler, E., Waschke, J., & Navab, N. (2016). Personalized augmented reality for anatomy education. *Clinical Anatomy*, 29(4), 446-453.
- Machado, J. A. D., Barbosa, J. M. P., & Ferreira, M. A. D. (2013). Student perspectives of imaging anatomy in undergraduate medical education. *Anat Sci Educ*, 6(3), 163-169. doi:10.1002/ase.1331
- Maresky, H. S., Oikonomou, A., Ali, I., Ditzkofsky, N., Pakkal, M., & Ballyk, B. (2019). Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. *Clin Anat*, 32(2), 238-243. doi:10.1002/ca.23292
- Marker, D. R., Bansal, A. K., Juluru, K., & Magid, D. (2010). Developing a radiology-based teaching approach for gross anatomy in the digital era. *Acad Radiol*, 17(8), 1057-1065. doi:10.1016/j.acra.2010.02.016
- Marker, D. R., Juluru, K., Long, C., & Magid, D. (2012). Strategic improvements for gross anatomy web-based teaching. *Anat Res Int*, 2012, 146262. doi:10.1155/2012/146262

- Marshak, D. W., Oakes, J., Hsieh, P. H., Chuang, A. Z., & Cleary, L. J. (2015). Outcomes of a rotational dissection system in gross anatomy. *Anat Sci Educ*, 8(5), 438-444. doi:10.1002/ase.1497
- Martinez, E. G., & Tuesca, R. (2014). Modified team-based learning strategy to improve human anatomy learning: A pilot study at the Universidad del Norte in Barranquilla, Colombia. *Anat Sci Educ*, 7(5), 399-405. doi:10.1002/ase.1444
- Mathiowetz, V., Yu, C. H., & Quake-Rapp, C. (2016). Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. *Anat Sci Educ*, 9(1), 52-59. doi:10.1002/ase.1528
- Mc Garvey, A., Hickey, A., & Conroy, R. (2015). The anatomy room: a positive learning experience for nursing students. *Nurse Educ Today*, 35(1), 245-250. doi:10.1016/j.nedt.2014.07.007
- McCulloch, C., Marango, S. P., Friedman, E. S., & Laitman, J. T. (2010). Living AnatoME: Teaching and Learning Musculoskeletal Anatomy through Yoga and Pilates. *Anat Sci Educ*, 3(6), 279-286. doi:http://dx.doi.org/10.1002/ase.181
- McLachlan, J. C., Bligh, J., Bradley, P., & Searle, J. (2004). Teaching anatomy without cadavers. *Med Educ*, 38(4), 418-424.
- McLachlan, J. C., & Patten, D. (2006). Anatomy teaching: ghosts of the past, present and future. *Med Educ*, 40(3), 243-253. doi:10.1111/j.1365-2929.2006.02401.x
- McNulty, J. A., Halama, J., & Espiritu, B. (2004). Evaluation of computer-aided instruction in the medical gross anatomy curriculum. *Clinical Anatomy*, 17(1), 73-78. doi:10.1002/ca.10188

- Melovitz-Vasan, C., DeFouw, D. O., & Vasan, N. S. (2013). How do we teach anatomy? Use of team-based learning strategy. In *Education in Anatomical Sciences* (pp. 33-44)
- Miller, R. (2000). Approaches to learning spatial relationships in gross anatomy: Perspective from wider principles of learning. *Clinical Anatomy*, 13(6), 439-443. doi:10.1002/1098-2353(2000)13:6<439::AID-CA8>3.0.CO;2-X
- Mitchell, R., & Batty, L. (2009). Undergraduate perspectives on the teaching and learning of anatomy. *ANZ J Surg*, 79(3), 118-121. doi:10.1111/j.1445-2197.2008.04826.x
- 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. *Ann Anat*, 218, 156-164. doi:10.1016/j.aanat.2018.02.015
- Mogali, S. R., Yeong, W. Y., Tan, H. K. J., Tan, G. J. S., Abrahams, P. H., Zary, N., . . . Ferenczi, M. A. (2018). Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. *Anat Sci Educ*, 11(1), 54-64. doi:10.1002/ase.1703
- Moro, C., Stromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anat Sci Educ*, 10(6), 549-559. doi:10.1002/ase.1696
- Moscova, M., Bryce, D. A., Sindhusake, D., & Young, N. (2015). Integration of medical imaging including ultrasound into a new clinical anatomy curriculum. *Anat Sci Educ*, 8(3), 205-220. doi:10.1002/ase.1481

- Murakami, T., Tajika, Y., Ueno, H., Awata, S., Hirasawa, S., Sugimoto, M., . . . Yorifuji, H. (2014). An integrated teaching method of gross anatomy and computed tomography radiology. *Anat Sci Educ*, 7(6), 438-449. doi:10.1002/ase.1430
- Musumeci, G., Loreto, C., Mazzone, V., Szychlińska, M. A., Castrogiovanni, P., & Castorina, S. (2014). Practical training on porcine hearts enhances students' knowledge of human cardiac anatomy. *Ann Anat*, 196(2-3), 92-99. doi:10.1016/j.aanat.2014.02.002
- Naeger, D. M., Conrad, M., Nguyen, J., Kohi, M. P., & Webb, E. M. (2013). Students teaching students: evaluation of a "near-peer" teaching experience. *Acad Radiol*, 20(9), 1177-1182. doi:10.1016/j.acra.2013.04.004
- Netterstrøm, I., & Kayser, L. (2008). Learning to be a doctor while learning anatomy. *Anat Sci Educ*, 1(4), 154-158. doi:10.1002/ase.31
- Nnodim, J. (1990). Learning human anatomy: by dissection or from prosections? *Med Educ*, 24(4), 389-395.
- O'Reilly, M. K., Reese, S., Herlihy, T., Geoghegan, T., Cantwell, C. P., Feeney, R. N., & Jones, J. F. (2016). Fabrication and assessment of 3D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. *Anat Sci Educ*, 9(1), 71-79. doi:10.1002/ase.1538
- Oakes, D. J., Hegedus, E. M., Ollerenshaw, S. L., Drury, H., & Ritchie, H. E. (2018). Using the Jigsaw Method to Teach Abdominal Anatomy. *Anat Sci Educ*. doi:10.1002/ase.1802
- Oh, C.-S., Won, H.-S., Kim, K.-J., & Jang, D.-S. (2011). "Digit Anatomy": A New Technique for Learning Anatomy Using Motor Memory. *Anat Sci Educ*, 4(3), 132-141. doi:http://dx.doi.org/10.1002/ase.223

- Op Den Akker, J. W., Bohnen, A., Oudegeest, W. J., & Hillen, B. (2002). Giving color to a new curriculum: Bodypaint as a tool in medical education. *Clinical Anatomy*, 15(5), 356-362. doi:10.1002/ca.10049
- Pabst, R., Westermann, J., & Lippert, H. (1986). Integration of clinical problems in teaching gross anatomy: living anatomy, X-ray anatomy, patient presentations, and films depicting clinical problems. *The Anatomical Record*, 215(1), 92-94. doi:10.1002/ar.1092150114
- Pais, D., Casal, D., Mascarenhas-Lemos, L., Barata, P., Moxham, B. J., & Goyri-O'Neill, J. (2017). Outcomes and satisfaction of two optional cadaveric dissection courses: A 3-year prospective study. *Anat Sci Educ*, 10(2), 127-136. doi:10.1002/ase.1638
- Pan, S., Cheng, X., Zhou, Y., Li, K., & Yang, X. (2017). Seeking the Optimal Time for Integrated Curriculum in Jinan University School of Medicine. *International Journal of Higher Education*, 6(1), 25-33.
- Park, S. E., & Howell, T. H. (2015). Implementation of a flipped classroom educational model in a predoctoral dental course. *J Dent Educ*, 79(5), 563-570.
- Parker, L. M. (2002). Anatomical dissection: Why are we cutting it out? Dissection in undergraduate teaching. *ANZ J Surg*, 72(12), 910-912. doi:10.1046/j.1445-2197.2002.02596.x
- Parmar, S. K., & Rathinam, B. A. D. (2011). Introduction of Vertical Integration and Case-Based Learning in Anatomy for Undergraduate Physical Therapy and Occupational Therapy Students. *Anat Sci Educ*, 4(3), 170-173. doi:http://dx.doi.org/10.1002/ase.225

- Patel, K. M., & Moxham, B. J. (2006). Attitudes of professional anatomists to curricular change. *Clinical Anatomy*, 19(2), 132-141. doi:10.1002/ca.20249
- Patel, K. M., & Moxham, B. J. (2008). The relationships between learning outcomes and methods of teaching anatomy as perceived by professional anatomists. *Clin Anat*, 21(2), 182-189. doi:10.1002/ca.20584
- Pather, N. (2015). Teaching anatomy: prosections and dissections. In *Teaching Anatomy* (pp. 213-221): Springer
- Pawlina, W., & Lachman, N. (2004). Dissection in learning and teaching gross anatomy: Rebuttal to McLachlan. *The Anatomical Record Part B: The New Anatomist*, 281B(1), 9-11. doi:10.1002/ar.b.20038
- Peeler, J., Bergen, H., & Bulow, A. (2018). Musculoskeletal Anatomy Education: Evaluating the Influence of Different Teaching and Learning Activities on Medical Students Perception and Academic Performance. *Ann Anat*, 219, 44-50. doi:10.1016/j.aanat.2018.05.004
- Pickering, J. D. (2017). Measuring Learning Gain: Comparing Anatomy Drawing Screencasts and Paper-Based Resources. *Anat Sci Educ*, 10(4), 307-316. doi:http://dx.doi.org/10.1002/ase.1666
- Pickles, K., Ivanusic, J. J., Xiao, J., Durward, C., Ryan, A. B., & Hayes, J. A. (2019). Peer Tutoring for Anatomy Workshops in Cambodia. *Anat Sci Educ*, 12(1), 82-89. doi:10.1002/ase.1804
- Pizzimenti, M. A., Pantazis, N., Sandra, A., Hoffmann, D. S., Lench, S., & Ferguson, K. J. (2016). Dissection and dissection-associated required experiences improve student performance in gross anatomy: Differences among quartiles. *Anat Sci Educ*, 9(3), 238-246. doi:10.1002/ase.1574



- Ramsey-Stewart, G., Burgess, A. W., & Hill, D. A. (2010). Back to the future: teaching anatomy by whole-body dissection. *Med J Aust*, 193(11-12), 668-671.
- Reeves, R. E., Aschenbrenner, J. E., Wordinger, R. J., Roque, R. S., & Sheedlo, H. J. (2004). Improved dissection efficiency in the human gross anatomy laboratory by the integration of computers and modern technology. *Clinical Anatomy*, 17(4), 337-344. doi:10.1002/ca.10245
- Rempell, J. S., Saldana, F., DiSalvo, D., Kumar, N., Stone, M. B., Chan, W., . . . Kohler, M. J. (2016). Pilot Point-of-Care Ultrasound Curriculum at Harvard Medical School: Early Experience. *West J Emerg Med*, 17(6), 734-740. doi: 10.5811/westjem.2016.8.31387
- Resuehr, D., & Makeeva, V. (2015). Development of a Flexible, Co-enrolled Teaching Assistant Program in an Anatomy Course with a Low Faculty-to-Student Ratio. *Med Sci Educ*, 25(1), 53-60. doi:10.1007/s40670-014-0099-x
- Rizzolo, L. J., Stewart, W. B., O'Brien, M., Haims, A., Rando, W., Abrahams, J., . . . Aden, M. (2006). Design principles for developing an efficient clinical anatomy course. *Med Teach*, 28(2), 142-151. doi: 10.1080/01421590500343065
- Saalu, L. C., Abraham, A. A., & Aina, W. O. (2010). Quantitative evaluation of third year medical students' perception and satisfaction from problem based learning in anatomy: A pilot study of the introduction of problem based learning into the traditional didactic medical curriculum in Nigeria. *Educational Research and Reviews*, 5(4), 193-200.
- Serrao, G., Tassoni, M., Magenta-Biasina, A. M., Mantero, A. G., Previtiera, A., Turci, M. C., . . . Bertolini, E. A. M. (2017). Virtual Dissection by Ultrasound: Probe

Handling in the First Year of Medical Education. *Ultrasound Int Open*, 3(4), E156-e162. doi:10.1055/s-0043-121983

Serrat, M. A., Dom, A. M., Buchanan, J. T., Jr., Williams, A. R., Efav, M. L., & Richardson, L. L. (2014). Independent learning modules enhance student performance and understanding of anatomy. *Anat Sci Educ*, 7(5), 406-416. doi:10.1002/ase.1438

Shaffer, K. (2004). Teaching Anatomy in the Digital World. *The New England Journal of Medicine*, 351(13), 1279-1281. doi:10.1056/NEJMp048100

Singh, V., & Kharb, P. (2013). A paradigm shift from teaching to learning gross anatomy: Meta-analysis of implications for instructional methods. *Journal of the Anatomical Society of India*, 62(1), 84-89. doi:10.1016/S0003-2778(13)80019-6

Siqueira Da Silva, I. C., Klein, G., & Brandao, D. M. (2017). *Segmented and detailed visualization of anatomical structures for health education*. Paper presented at the Proceedings - International Conference of the Chilean Computer Science Society, SCCC

Smith, C. F., & Mathias, H. S. (2010). Medical students' approaches to learning anatomy: students' experiences and relations to the learning environment. *Clinical Anatomy: The Official Journal of the American Association of Clinical Anatomists and the British Association of Clinical Anatomists*, 23(1), 106-114.

Smith, C. F., & Mathias, H. S. (2011). What impact does anatomy education have on clinical practice? *Clin Anat*, 24(1), 113-119. doi:10.1002/ca.21065

Smith, C. F., Tollemache, N., Covill, D., & Johnston, M. (2018a). Take away body parts! An investigation into the use of 3D-printed anatomical models in

undergraduate anatomy education. *Anat Sci Educ*, 11(1), 44-53. doi:10.1002/ase.1718

Smith, J. P., Kendall, J. L., & Royer, D. F. (2018b). Improved medical student perception of ultrasound using a paired anatomy teaching assistant and clinician teaching model. *Anat Sci Educ*, 11(2), 175-184. doi:10.1002/ase.1722

Snelling, J., Sahai, A., & Ellis, H. (2003). Attitudes of medical and dental students to dissection. *Clinical Anatomy*, 16(2), 165-172. doi:10.1002/ca.10113

Sritharan, K. (2005). The rise and fall of anatomy. *BMJ*, 331(Suppl S3), 509332. doi:10.1136/sbmj.0509332

Stewart, S., & Choudhury, B. (2015). Mobile technology: Creation and use of an iBook to teach the anatomy of the brachial plexus. *Anat Sci Educ*, 8(5), 429-437. doi:10.1002/ase.1501

Stirling, A., & Birt, J. (2014). An enriched multimedia eBook application to facilitate learning of anatomy. *Anat Sci Educ*, 7(1), 19-27. doi:10.1002/ase.1373

Sugand, K., Abrahams, P., & Khurana, A. (2010). The anatomy of anatomy: a review for its modernization. *Anat Sci Educ*, 3(2), 83-93. doi:10.1002/ase.139

Sweeney, K., Hayes, J. A., & Chiavaroli, N. (2014). Does spatial ability help the learning of anatomy in a biomedical science course? *Anat Sci Educ*, 7(4), 289-294.

Sweetman, G. M., Crawford, G., Hird, K., & Fear, M. W. (2013). The benefits and limitations of using ultrasonography to supplement anatomical understanding. *Anat Sci Educ*, 6(3), 141-148. doi:10.1002/ase.1327

- Sytsma, T. T., Haller, E. P., Youdas, J. W., Krause, D. A., Hellyer, N. J., Pawlina, W., & Lachman, N. (2015). Long-term effect of a short interprofessional education interaction between medical and physical therapy students. *Anat Sci Educ*, 8(4), 317-323. doi:10.1002/ase.1546
- Tam, M. D. B. S., Hart, A. R., Williams, S., Heylings, D., & Leinster, S. (2009). Is learning anatomy facilitated by computer-aided learning? A review of the literature. *Med Teach*, 31(9), e393-e396. doi:10.1080/01421590802650092
- Tam, M. D. B. S., Hart, A. R., Williams, S. M., Holland, R., Heylings, D., & Leinster, S. (2010). Evaluation of a computer program ('disect') to consolidate anatomy knowledge: A randomised-controlled trial. *Med Teach*, 32(3), e138-e142. doi: 10.3109/01421590903144110
- ten Brinke, B., Klitsie, P. J., Timman, R., Busschbach, J. J., Lange, J. F., & Kleinrensink, G. J. (2014). Anatomy education and classroom versus laparoscopic dissection-based training: a randomized study at one medical school. *Acad Med*, 89(5), 806-810. doi:10.1097/acm.0000000000000223
- Thomas, K. J., Denham, B. E., & Dinolfo, J. D. (2011). Perceptions among Occupational and Physical Therapy Students of a Nontraditional Methodology for Teaching Laboratory Gross Anatomy. *Anat Sci Educ*, 4(2), 71-77. doi:http://dx.doi.org/10.1002/ase.208
- Thomas, R. G., John, N. W., & Delieu, J. M. (2010). Augmented reality for anatomical education. *J Vis Commun Med*, 33(1), 6-15. doi: 10.3109/17453050903557359
- Topping, D. B. (2014). Gross Anatomy Videos: Student Satisfaction, Usage, and Effect on Student Performance in a Condensed Curriculum. *Anat Sci Educ*, 7(4), 273-279. doi:http://dx.doi.org/10.1002/ase.1405

- Torres, A., Staskiewicz, G. J., Lisiecka, J., Pietrzyk, L., Czekałło, M., Arancibia, C. U., . . . Torres, K. (2016). Bridging the gap between basic and clinical sciences: A description of a radiological anatomy course. *Anat Sci Educ*, 9(3), 295-303. doi:10.1002/ase.1577
- Turney, B. W. (2007). Anatomy in a modern medical curriculum. *Annals of The Royal College of Surgeons of England*, 89(2), 104-107. doi:10.1308/003588407X168244
- Van Nuland, S. E., Roach, V. A., Wilson, T. D., & Belliveau, D. J. (2015). Head to head: The role of academic competition in undergraduate anatomical education: Head to Head. *Anat Sci Educ*, 8(5), 404-412. doi:10.1002/ase.1498
- Van Nuland, S. E., & Rogers, K. A. (2017). The skeletons in our closet: E-learning tools and what happens when one side does not fit all. *Anat Sci Educ*, 10(6), 570-588. doi:10.1002/ase.1708
- Vázquez, R., Riesco, J. M., Juanes, J. A., Blanco, E., Rubio, M., & Carretero, J. (2007). Educational strategies applied to the teaching of anatomy. The evolution of resources. *European Journal of Anatomy*, 11(S1), 31-43.
- Vorstenbosch, M., Bolhuis, S., van Kuppeveld, S., Kooloos, J., & Laan, R. (2011). Properties of publications on anatomy in medical education literature. *Anat Sci Educ*, 4(2), 105-114. doi:10.1002/ase.210
- Wang, J., Zhang, W., Qin, L., Zhao, J., Zhang, S., Gu, J., & Zhou, C. (2010). Problem-Based Learning in Regional Anatomy Education at Peking University. *Anat Sci Educ*, 3(3), 121-126. doi:http://dx.doi.org/10.1002/ase.151

- Waters, J. R., Van Meter, P., Perrotti, W., Drogo, S., & Cyr, R. J. (2011). Human Clay Models versus Cat Dissection: How the Similarity between the Classroom and the Exam Affects Student Performance. *Adv Physiol Educ*, 35(2), 227-236. doi:<http://dx.doi.org/10.1152/advan.00030.2009>
- Waterston, S. W., & Stewart, I. J. (2005). Survey of clinicians' attitudes to the anatomical teaching and knowledge of medical students. *Clinical Anatomy*, 18(5), 380-384. doi:10.1002/ca.20101
- Watmough, S. D., O'Sullivan, H., & Taylor, D. C. M. (2010). Graduates from a reformed undergraduate medical curriculum based on Tomorrow's Doctors evaluate the effectiveness of their curriculum 6 years after graduation through interviews. *BMC Med Educ*, 10(1), 65-65. doi:10.1186/1472-6920-10-65
- Wearn, A., & Bhoopatkar, H. (2006). Evaluation of consent for peer physical examination: students reflect on their clinical skills learning experience. *Med Educ*, 40(10), 957-964. doi:10.1111/j.1365-2929.2006.02557.x
- Wilhelmsson, N., Dahlgren, L. O., Hult, H., Scheja, M., Lonka, K., Josephson, A., . . . Institutionen för beteendevetenskap och, I. (2010). The anatomy of learning anatomy. *Adv Health Sci Educ Theory Pract*, 15(2), 153-165. doi:10.1007/s10459-009-9171-5
- Wilkinson, K., & Barter, P. (2015). Do Mobile Learning Devices Enhance Learning in Higher Education Anatomy Classrooms? In (pp. 1-8): International Association for the Development of the Information Society
- Williams, S. R., Thompson, K. L., Notebaert, A. J., & Sinning, A. R. (2019). Prosection or Dissection: Which is Best for Teaching the Anatomy of the Hand and Foot? *Anat Sci Educ*, 12(2), 173-180. doi:10.1002/ase.1808

- Wilson, A. B., Brown, K. M., Misch, J., Miller, C. H., Klein, B. A., Taylor, M. A., . . . Lazarus, M. D. (2019). Breaking with Tradition: A Scoping Meta-Analysis Analyzing the Effects of Student-Centered Learning and Computer-Aided Instruction on Student Performance in Anatomy: Effectiveness of Student Centered and Computer-Aided Learning in Anatomy. *Anat Sci Educ*, 12(1), 61-73. doi:10.1002/ase.1789
- Winkelmann, A. (2007). Anatomical dissection as a teaching method in medical school: a review of the evidence. *Med Educ*, 41(1), 15-22. doi:10.1111/j.1365-2929.2006.02625.x
- Wright, S. J. (2012). Student perceptions of an upper-level, undergraduate human anatomy laboratory course without cadavers. *Anat Sci Educ*, 5(3), 146-157. doi:10.1002/ase.1265
- Wu, A. M., Wang, K., Wang, J. S., Chen, C. H., Yang, X. D., Ni, W. F., & Hu, Y. Z. (2018). The addition of 3D printed models to enhance the teaching and learning of bone spatial anatomy and fractures for undergraduate students: a randomized controlled study. *Ann Transl Med*, 6(20), 403. doi:10.21037/atm.2018.09.59
- Yamine, K. (2014). The current status of anatomy knowledge: where are we now? Where do we need to go and how do we get there? *Teach Learn Med*, 26(2), 184-188. doi:10.1080/10401334.2014.883985
- Yeom, S., Choi-Lundberg, D., Fluck, A., & Sale, A. (2013). *User Acceptance of a Haptic Interface for Learning Anatomy*.
- Yi, X., Ding, C., Xu, H., Huang, T., Kang, D., & Wang, D. (2019). Three-Dimensional Printed Models in Anatomy Education of the Ventricular System: A Randomized Controlled Study. *World Neurosurg*. doi:10.1016/j.wneu.2019.01.204

Zumwalt, A. C., Lufler, R. S., Monteiro, J., & Shaffer, K. (2010). Building the Body: Active Learning Laboratories that Emphasize Practical Aspects of Anatomy and Integration with Radiology. *Anat Sci Educ*, 3(3), 134-140. doi:<http://dx.doi.org/10.1002/ase.153>



## Appendix: Supplemental References

- Abed Rabbo, F., Garrigues, F., Lefèvre, C., & Seizeur, R. (2016). Interactive anatomical teaching: Integrating radiological anatomy within topographic anatomy. *Morphologie, 100*(328), 17-23. doi:<https://doi.org/10.1016/j.morpho.2015.08.004>
- Abu Eid, R., Ewan, K., Foley, J., Oweis, Y., & Jayasinghe, J. (2013). Self-directed study and carving tooth models for learning tooth morphology: perceptions of students at the University of Aberdeen, Scotland. *J Dent Educ, 77*(9), 1147-1153.
- Agius, A., Calleja, N., Camenzuli, C., Sultana, R., Pullicino, R., Zammit, C., . . . Pomara, C. (2018). Perceptions of first-year medical students towards learning anatomy using cadaveric specimens through peer teaching. *Anat Sci Educ, 11*(4), 346-357. doi:10.1002/ase.1751
- Agius, A., & Stabile, I. (2018). Undergraduate peer assisted learning tutors' performance in summative anatomy examinations: a pilot study. *Int J Med Educ, 9*, 93-98. doi:10.5116/ijme.5aa3.e2a6
- Ahmad, M., Sleiman, N. H., Thomas, M., Kashani, N., & Ditmyer, M. M. (2016). Use of High-Definition Audiovisual Technology in a Gross Anatomy Laboratory: Effect on Dental Students' Learning Outcomes and Satisfaction. *J Dent Educ, 80*(2), 128-132.
- Al-Madi, E. M., Celur, S. L., & Nasim, M. (2018). Effectiveness of PBL methodology in a hybrid dentistry program to enhance students' knowledge and confidence. (a pilot study). *BMC Med Educ, 18*(1), 270. doi:10.1186/s12909-018-1392-y

- Alfalah, S. F. M., Falah, J. F. M., Alfalah, T., Elfalah, M., Muhaidat, N., & Falah, O. (2018). A comparative study between a virtual reality heart anatomy system and traditional medical teaching modalities. *Virtual Reality*. doi:10.1007/s10055-018-0359-y
- Alsaid, B., & Bertrand, M. (2016). Students' memorization of anatomy, influence of drawing. *Morphologie*, 100(328), 2-6. doi:10.1016/j.morpho.2015.11.001
- Anand, T., Kishore, J., Ingle, G., & Grover, S. (2018). Perception about use of comics in medical and nursing education among students in health professions' schools in New Delhi. *Education for Health: Change in Learning and Practice*, 31(2), 125-129. doi:10.4103/efh.EfH\_298\_15
- Ang, E. T., Chan, J. M., Gopal, V., & Li Shia, N. (2018). Gamifying anatomy education. *Clin Anat*, 31(7), 997-1005. doi:10.1002/ca.23249
- Anstey, L. M. (2017). "Applying Anatomy to Something I Care About": Authentic Inquiry Learning and Student Experiences of an Inquiry Project. *Anat Sci Educ*, 10(6), 538-548. doi:http://dx.doi.org/10.1002/ase.1690
- Anstey, L. M., Michels, A., Szymus, J., Law, W., Edwin Ho, M. H., Qu, F., . . . Chow, N. (2014). Reflections as near-peer facilitators of an inquiry project for undergraduate anatomy: Successes and challenges from a term of trial-and-error. *Anat Sci Educ*, 7(1), 64-70. doi:10.1002/ase.1383
- Arya, R., Morrison, T., Zumwalt, A., & Shaffer, K. (2013). Making education effective and fun: stations-based approach to teaching radiology and anatomy to third-year medical students. *Acad Radiol*, 20(10), 1311-1318. doi:10.1016/j.acra.2013.07.012

- Attardi, S. M., Choi, S., Barnett, J., & Rogers, K. A. (2016). Mixed methods student evaluation of an online systemic human anatomy course with laboratory. *Anat Sci Educ*, 9(3), 272-285. doi:10.1002/ase.1584
- Aversi-Ferreira, T. A., do Nascimento, G. N. L., Vera, I., & Lucchese, R. (2010). The practice of dissection as teaching methodology in anatomy applied to medical education. *International Journal of Morphology*, 28(1), 265-272. doi: 10.4067/S0717-95022010000100039
- Backhouse, M., Fitzpatrick, M., Hutchinson, J., Thandi, C. S., & Keenan, I. D. (2017). Improvements in anatomy knowledge when utilizing a novel cyclical "Observe-Reflect-Draw-Edit-Repeat" learning process. *Anat Sci Educ*, 10(1), 7-22. doi:10.1002/ase.1616
- Baker, E. W., Slott, P. A., Terracio, L., & Cunningham, E. P. (2013). An innovative method for teaching anatomy in the predoctoral dental curriculum. *J Dent Educ*, 77(11), 1498-1507.
- Bareither, M. L., Arbel, V., Growe, M., Muszczynski, E., Rudd, A., & Marone, J. R. (2013). Clay Modeling versus Written Modules as Effective Interventions in Understanding Human Anatomy. *Anat Sci Educ*, 6(3), 170-176. doi:http://dx.doi.org/10.1002/ase.1321
- Barton, C. E., Williams, C. L., Halle, J. S., & McGrew, L. (2018). Graduate and Undergraduate Faculty Collaboration Utilizing Peer Observation to Enhance Educational Opportunities for Students and Faculty: A Case Example. *Journal of the Scholarship of Teaching and Learning*, 18(3), 189-211.
- Battulga, B., Konishi, T., Tamura, Y., & Moriguchi, H. (2012). The effectiveness of an interactive 3-dimensional computer graphics model for medical education. *Interact J Med Res*, 1(2), e2. doi:10.2196/ijmr.2172

- Bell, L. T., & Evans, D. J. (2014). Art, anatomy, and medicine: Is there a place for art in medical education? *Anat Sci Educ*, 7(5), 370-378. doi:10.1002/ase.1435
- Bergman, E. M., de Bruin, A. B., Herrler, A., Verheijen, I. W., Scherpbier, A. J., & van der Vleuten, C. P. (2013). Students' perceptions of anatomy across the undergraduate problem-based learning medical curriculum: a phenomenographical study. *BMC Med Educ*, 13, 152. doi: 10.1186/1472-6920-13-152
- Berney, S., Bétrancourt, M., Molinari, G., & Hoyek, N. (2015). How Spatial Abilities and Dynamic Visualizations Interplay When Learning Functional Anatomy with 3D Anatomical Models. *Anat Sci Educ*, 8(5), 452-462. doi:http://dx.doi.org/10.1002/ase.1524
- Bohl, M., Francois, W., & Gest, T. (2011). Self-guided clinical cases for medical students based on postmortem CT scans of cadavers. *Clin Anat*, 24(5), 655-663. doi:10.1002/ca.21143
- Bork, F., Stratmann, L., Enssle, S., Eck, U., Navab, N., Waschke, J., & Kugelmann, D. (2019). The Benefits of an Augmented Reality Magic Mirror System for Integrated Radiology Teaching in Gross Anatomy. *Anat Sci Educ*. doi: 10.1002/ase.1864
- Brown, B., Adhikari, S., Marx, J., Lander, L., & Todd, G. L. (2012). Introduction of ultrasound into gross anatomy curriculum: perceptions of medical students. *J Emerg Med*, 43(6), 1098-1102. doi:10.1016/j.jemermed.2012.01.041
- Brown, P. M., Hamilton, N. M., & Denison, A. R. (2012). A novel 3D stereoscopic anatomy tutorial. *Clin Teach*, 9(1), 50-53. doi:10.1111/j.1743-498X.2011.00488.x

- Bruno, P. A., Love Green, J. K., Illerbrun, S. L., Holness, D. A., Illerbrun, S. J., Haus, K. A., . . . Sveinson, K. L. (2016). Students helping students: Evaluating a pilot program of peer teaching for an undergraduate course in human anatomy. *Anat Sci Educ*, 9(2), 132-142. doi:10.1002/ase.1543
- Buenting, M., Mueller, T., Raupach, T., Luers, G., Wehrenberg, U., Gehl, A., & Anders, S. (2016). Post mortem CT scans as a supplementary teaching method in gross anatomy. *Ann Anat*, 208, 165-169. doi:10.1016/j.aanat.2016.05.003
- Burgess, A., & Ramsey-Stewart, G. (2015). Anatomy by whole body dissection: a focus group study of students' learning experience. *Adv Med Educ Pract*, 6, 533-537. doi:10.2147/amep.S86583
- Cai, B., Rajendran, K., Bay, B. H., Lee, J., & Yen, C. C. (2018). The Effects of a Functional Three-dimensional (3D) Printed Knee Joint Simulator in Improving Anatomical Spatial Knowledge. *Anat Sci Educ*. doi:10.1002/ase.1847
- Canty, D. J., Hayes, J. A., Story, D. A., & Royse, C. F. (2015). Ultrasound simulator-assisted teaching of cardiac anatomy to preclinical anatomy students: A pilot randomized trial of a three-hour learning exposure. *Anat Sci Educ*, 8(1), 21-30. doi:10.1002/ase.1452
- Carter, J. L., Hocum, G., Pellicer, R., Patel, A., & Benninger, B. (2016). Integration of 3D/4D Ultrasound in Teaching Medical Anatomy. *Med Sci Educ*, 26(3), 343-348. doi:10.1007/s40670-016-0271-6
- Carter, J. L., Patel, A., Hocum, G., & Benninger, B. (2017). Thyroid gland visualization with 3D/4D ultrasound: integrated hands-on imaging in anatomical dissection laboratory. *Surg Radiol Anat*, 39(5), 567-572. doi:10.1007/s00276-016-1775-x

- Chen, S., Pan, Z., Wu, Y., Gu, Z., Li, M., Liang, Z., . . . Pan, H. (2017). The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trial. *Sci Rep*, 7(1), 575. doi:10.1038/s41598-017-00647-1
- Chimmalgi, M. (2019). Interactive Lecture in the Dissection Hall: Transforming Passive Lecture into a Dynamic Learning Experience. *Anat Sci Educ*, 12(2), 191-199. doi:10.1002/ase.1803
- Choi-Lundberg, D. L., Cuellar, W. A., & Williams, A.-M. M. (2016). Online Dissection Audio-Visual Resources for Human Anatomy: Undergraduate Medical Students' Usage and Learning Outcomes. *Anat Sci Educ*, 9(6), 545-554. doi:http://dx.doi.org/10.1002/ase.1607
- Christensen, J. D., Schmalz, N. A., Challyandra, L., & Stark, M. E. (2018). Establishment of a Peer Teaching Assistant Program for Preclinical Human Gross Anatomy Curricula. *Med Sci Educ*, 28(4), 765-772. doi:10.1007/s40670-018-0604-8
- Codd, A. M., & Choudhury, B. (2011). Virtual Reality Anatomy: Is It Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy? *Anat Sci Educ*, 4(3), 119-125. doi:http://dx.doi.org/10.1002/ase.214
- Cui, D., Wilson, T. D., Rockhold, R. W., Lehman, M. N., & Lynch, J. C. (2017). Evaluation of the effectiveness of 3D vascular stereoscopic models in anatomy instruction for first year medical students. *Anat Sci Educ*, 10(1), 34-45. doi:10.1002/ase.1626
- Dettmer, S., Schmiedl, A., Meyer, S., Giesemann, A., Pabst, R., Weidemann, J., . . . Kirchhoff, T. (2013). Radiological anatomy - evaluation of integrative education in radiology. *Rofo*, 185(9), 838-843. doi:10.1055/s-0033-1335048

- Dickman, N., Barash, A., Reis, S., & Karasik, D. (2017). Students as anatomy near-peer teachers: a double-edged sword for an ancient skill. *BMC Med Educ*, 17(1), 156. doi:10.1186/s12909-017-0996-y
- Duran, C. E. P., Bahena, E. N., Rodriguez, M. d. I. A. G., Baca, G. J., Uresti, A. S., Elizondo-Omana, R. E., & Lopez, S. G. (2012). Near-Peer Teaching in an Anatomy Course with a Low Faculty-to-Student Ratio. *Anat Sci Educ*, 5(3), 171-176. doi:http://dx.doi.org/10.1002/ase.1269
- Fergusson, S. J., Aka, J. J., Hennessy, C. M., Wilson, A. J., Parson, S. H., Harrison, E. M., . . . Gillingwater, T. H. (2018). Examining the impact of audience response systems on student performance in anatomy education: a randomised controlled trial. *Scott Med J*, 63(1), 16-21. doi: 10.1177/0036933017741409
- Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., García, S., & Barcia, J. M. (2015). ARBOOK: Development and Assessment of a Tool Based on Augmented Reality for Anatomy. *Journal of Science Education and Technology*, 24(1), 119-124. doi:http://dx.doi.org/10.1007/s10956-014-9526-4
- Findlater, G. S., Kristmundsdottir, F., Parson, S. H., & Gillingwater, T. H. (2012). Development of a supported self-directed learning approach for anatomy education. *Anat Sci Educ*, 5(2), 114-121. doi:10.1002/ase.1255
- Finn, G. M., & McLachlan, J. C. (2010). A Qualitative Study of Student Responses to Body Painting. *Anat Sci Educ*, 3(1), 33-38.
- Finn, G. M., White, P. M., & Abdelbagi, P. M. (2011). The Impact of Color and Role on Retention of Knowledge: A Body-Painting Study within Undergraduate Medicine. *Anat Sci Educ*, 4(6), 311-317. doi:http://dx.doi.org/10.1002/ase.253

- Fleagle, T. R., Borcharding, N. C., Harris, J., & Hoffmann, D. S. (2018). Application of Flipped Classroom Pedagogy to the Human Gross Anatomy Laboratory: Student Preferences and Learning Outcomes. *Anat Sci Educ*, 11(4), 385-396. doi:<http://dx.doi.org/10.1002/ase.1755>
- Fritz, D., Hu, A., Wilson, T., Ladak, H., Haase, P., & Fung, K. (2011). Long-term retention of a 3-dimensional educational computer model of the larynx: a follow-up study. *Arch Otolaryngol Head Neck Surg*, 137(6), 598-603. doi: 10.1001/archoto.2011.76
- Ghorbani, N., Karbalay-Doust, S., & Noorafshan, A. (2014). Is a Team-based Learning Approach to Anatomy Teaching Superior to Didactic Lecturing? *Sultan Qaboos Univ Med J*, 14(1), e120-125.
- Green, R. A., Farchione, D., Hughes, D. L., & Chan, S. P. (2014). Participation in asynchronous online discussion forums does improve student learning of gross anatomy. *Anat Sci Educ*, 7(1), 71-76. doi:10.1002/ase.1376
- Green, R. A., & Hughes, D. L. (2013). Student Outcomes Associated with Use of Asynchronous Online Discussion Forums in Gross Anatomy Teaching. *Anat Sci Educ*, 6(2), 101-106. doi:<http://dx.doi.org/10.1002/ase.1310>
- Green, R. A., & Whitburn, L. Y. (2016). Impact of introduction of blended learning in gross anatomy on student outcomes. *Anat Sci Educ*, 9(5), 422-430. doi: 10.1002/ase.1602
- Greene, S. J. (2018). The Use and Effectiveness of Interactive Progressive Drawing in Anatomy Education. *Anat Sci Educ*, 11(5), 445-460. doi:<http://dx.doi.org/10.1002/ase.1784>



- Griksaitis, M. J., Sawdon, M. A., & Finn, G. M. (2012). Ultrasound and Cadaveric Prosections as Methods for Teaching Cardiac Anatomy: A Comparative Study. *Anat Sci Educ*, 5(1), 20-26. doi:http://dx.doi.org/10.1002/ase.259
- Hampton, B. S., & Sung, V. W. (2010). Improving medical student knowledge of female pelvic floor dysfunction and anatomy: a randomized trial. *Am J Obstet Gynecol*, 202(6), 601.e601-608. doi:10.1016/j.ajog.2009.08.038
- Herrmann, G., Woermann, U., & Schlegel, C. (2015). Interprofessional education in anatomy: Learning together in medical and nursing training. *Anat Sci Educ*, 8(4), 324-330. doi:10.1002/ase.1506
- Holland, J. C., & Pawlikowska, T. (2018). Undergraduate Medical Students' Usage and Perceptions of Anatomical Case-Based Learning: Comparison of Facilitated Small Group Discussions and eLearning Resources. *Anat Sci Educ*. doi:10.1002/ase.1824
- Horneffer, A., Fassnacht, U., Oechsner, W., Huber-Lang, M., Boeckers, T. M., & Boeckers, A. (2016). Effect of didactically qualified student tutors on their tutees' academic performance and tutor evaluation in the gross anatomy course. *Ann Anat*, 208, 170-178. doi:10.1016/j.aanat.2016.05.008
- Hoyek, N., Collet, C., Di Rienzo, F., De Almeida, M., & Guillot, A. (2014). Effectiveness of three-dimensional digital animation in teaching human anatomy in an authentic classroom context. *Anat Sci Educ*, 7(6), 430-437. doi:10.1002/ase.1446
- Inuwa, I. M. (2012). Perceptions and Attitudes of First-Year Medical Students on a Modified Team-Based Learning (TBL) Strategy in Anatomy. *Sultan Qaboos Univ Med J*, 12(3), 336-343.

- Ivanusic, J., Cowie, B., & Barrington, M. (2010). Undergraduate Student Perceptions of the Use of Ultrasonography in the Study of "Living Anatomy". *Anat Sci Educ*, 3(6), 318-322. doi:<http://dx.doi.org/10.1002/ase.180>
- Jaffar, A. A. (2012). YouTube: An emerging tool in anatomy education. *Anat Sci Educ*, 5(3), 158-164. doi:10.1002/ase.1268
- James, H. K., Chapman, A. W. P., Dhukaram, V., Wellings, R., & Abrahams, P. (2018). Learning anatomy of the foot and ankle using sagittal plastinates: A prospective randomized educational trial. *Foot (Edinb)*, 38, 34-38. doi:10.1016/j.foot.2018.11.004
- Janssen, A., Shaw, T., Goodyear, P., Kerfoot, B. P., & Bryce, D. (2015). A little healthy competition: using mixed methods to pilot a team-based digital game for boosting medical student engagement with anatomy and histology content. *BMC Med Educ*, 15, 173. doi:10.1186/s12909-015-0455-6
- Jariyapong, P., Punsawad, C., Bunratsami, S., & Kongthong, P. (2016). Body painting to promote self-active learning of hand anatomy for preclinical medical students. *Med Educ Online*, 21, 30833. doi:10.3402/meo.v21.30833
- Jarral, S. A., Mehboob, F., & Ashraf, S. (2017). Students' response on the effectiveness of CBL in learning Gross anatomy in an undergraduate course. *Pakistan Journal of Medical and Health Sciences*, 11(3), 917-921.
- Jurjus, R. A., Dimorier, K., Brown, K., Slaby, F., Shokoohi, H., Boniface, K., & Liu, Y. T. (2014). Can anatomists teach living anatomy using ultrasound as a teaching tool? *Anat Sci Educ*, 7(5), 340-349. doi:10.1002/ase.1417
- Keedy, A. W., Durack, J. C., Sandhu, P., Chen, E. M., O'Sullivan, P. S., & Breiman, R. S. (2011). Comparison of Traditional Methods with 3D Computer Models in

the Instruction of Hepatobiliary Anatomy. *Anat Sci Educ*, 4(2), 84-91.  
doi:<http://dx.doi.org/10.1002/ase.212>

Kelly, D., Hoang, T. N., Reinoso, M., Joukhadar, Z., Clements, T., & Vetere, F. (2018). Augmented reality learning environment for physiotherapy education. *Physical Therapy Reviews*, 23(1), 21-28. doi:  
10.1080/10833196.2018.1447256

Kharb, P., & Samanta, P. P. (2016). Blended learning approach for teaching and learning anatomy: Students' and teachers' perspective. *Journal of the Anatomical Society of India*, 65(1), 43-47. doi:10.1016/j.jasi.2016.06.001

Kinirons, S. A., Reddin, V. M., & Maguffin, J. (2018). Effects of Alternating Dissection with Peer Teaching and Faculty Prosected Cadaver Demonstrations in a Physical Therapy and Occupational Therapy Gross Anatomy Course. *Anat Sci Educ*. doi:10.1002/ase.1833

Knobe, M., Carow, J. B., Ruesseler, M., Leu, B. M., Simon, M., Beckers, S. K., . . . Pape, H. C. (2012). Arthroscopy or ultrasound in undergraduate anatomy education: a randomized cross-over controlled trial. *BMC Med Educ*, 12, 85. doi:10.1186/1472-6920-12-85

Kolossvary, M., Szekely, A. D., Gerber, G., Merkely, B., & Maurovich-Horvat, P. (2017). CT Images Are Noninferior to Anatomic Specimens in Teaching Cardiac Anatomy-A Randomized Quantitative Study. *J Am Coll Radiol*, 14(3), 409-415.e402. doi:10.1016/j.jacr.2016.09.050

Kondrashova, T., De Wan, D., Briones, M. U., & Kondrashov, P. (2017). Integration of ultrasound imaging into pre-clinical dental education. *Eur J Dent Educ*, 21(4), 228-234. doi:10.1111/eje.12205

- Kong, X., Nie, L., Zhang, H., Wang, Z., Ye, Q., Tang, L., . . . Huang, W. (2016). Do Three-dimensional Visualization and Three-dimensional Printing Improve Hepatic Segment Anatomy Teaching? A Randomized Controlled Study. *J Surg Educ*, 73(2), 264-269. doi:10.1016/j.jsurg.2015.10.002
- Kooloos, J. G., Schepens-Franke, A. N., Bergman, E. M., Donders, R. A., & Vorstenbosch, M. A. (2014). Anatomical knowledge gain through a clay-modeling exercise compared to live and video observations. *Anat Sci Educ*, 7(6), 420-429. doi:10.1002/ase.1443
- Kotzé, S. H., Mole, C. G., & Greyling, L. M. (2012). The translucent cadaver: an evaluation of the use of full body digital X-ray images and drawings in surface anatomy education. *Anat Sci Educ*, 5(5), 287-294.
- Kugelmann, D., Stratmann, L., Nuhlen, N., Bork, F., Hoffmann, S., Samarbarksh, G., . . . Waschke, J. (2018). An Augmented Reality magic mirror as additive teaching device for gross anatomy. *Ann Anat*, 215, 71-77. doi:10.1016/j.aanat.2017.09.011
- Lai, H. L., Perng, S. J., & Huang, C. Y. (2019). Nursing Students' Perceptions of a Silent Mentor Program in an Anatomy Course. *Anat Sci Educ*. doi:10.1002/ase.1863
- Larkin, T. A., & McAndrew, D. J. (2013). Factors influencing students' decisions to participate in a short "dissection experience" within a systemic anatomy course. *Anat Sci Educ*, 6(4), 225-231. doi:10.1002/ase.1323
- Lazarus, L., Sookrajh, R., & Satyapal, K. S. (2017). Tablet technology in medical education in South Africa: a mixed methods study. *BMJ Open*, 7(7), e013871. doi:10.1136/bmjopen-2016-013871

- Lefroy, H., Burdon-Bailey, V., Bhangu, A., & Abrahams, P. (2011). A novel technique for teaching the brachial plexus. *Clin Teach*, 8(3), 196-199. doi:10.1111/j.1743-498X.2011.00448.x
- Li, Z., Li, Z., Xu, R., Li, M., Li, J., Liu, Y., . . . Chen, Z. (2015). Three-dimensional printing models improve understanding of spinal fracture-A randomized controlled study in China. *Sci Rep*, 5. doi:10.1038/srep11570
- Lim, K. H. A., Loo, Z. Y., Goldie, S. J., Adams, J. W., & McMenamin, P. G. (2016). Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. *Anat Sci Educ*, 9(3), 213-221. doi:10.1002/ase.1573
- Lufler, R. S., Lazarus, M. D., & Stefanik, J. J. (2019). The Spectrum of Learning and Teaching: The Impact of a Fourth-Year Anatomy Course on Medical Student Knowledge and Confidence. *Anat Sci Educ*. doi:10.1002/ase.1872
- Lufler, R. S., Zumwalt, A. C., Romney, C. A., & Hoagland, T. M. (2010). Incorporating Radiology into Medical Gross Anatomy: Does the Use of Cadaver CT Scans Improve Students' Academic Performance in Anatomy? *Anat Sci Educ*, 3(2), 56-63.
- Machado, J. A. D., Barbosa, J. M. P., & Ferreira, M. A. D. (2013). Student perspectives of imaging anatomy in undergraduate medical education. *Anat Sci Educ*, 6(3), 163-169. doi:10.1002/ase.1331
- Maresky, H. S., Oikonomou, A., Ali, I., Ditkofsky, N., Pakkal, M., & Ballyk, B. (2019). Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. *Clin Anat*, 32(2), 238-243. doi:10.1002/ca.23292

- Marker, D. R., Bansal, A. K., Juluru, K., & Magid, D. (2010). Developing a radiology-based teaching approach for gross anatomy in the digital era. *Acad Radiol*, 17(8), 1057-1065. doi:10.1016/j.acra.2010.02.016
- Marker, D. R., Juluru, K., Long, C., & Magid, D. (2012). Strategic improvements for gross anatomy web-based teaching. *Anat Res Int*, 2012, 146262. doi: 10.1155/2012/146262
- Marshak, D. W., Oakes, J., Hsieh, P. H., Chuang, A. Z., & Cleary, L. J. (2015). Outcomes of a rotational dissection system in gross anatomy. *Anat Sci Educ*, 8(5), 438-444. doi:10.1002/ase.1497
- Marsland, M. J., Tomic, D., Brian, P. L., & Lazarus, M. D. (2018a). Abdominal Anatomy Tutorial Using a Medical Imaging Platform. *MedEdPORTAL*, 14, 10748. doi:10.15766/mep\_2374-8265.10748
- Marsland, M. J., Tomic, D., Brian, P. L., & Lazarus, M. D. (2018b). Pelvis Anatomy Tutorial Using Radiological Images. *MedEdPORTAL*, 14, 10778. doi: 10.15766/mep\_2374-8265.10778
- Martinez, E. G., & Tuesca, R. (2014). Modified team-based learning strategy to improve human anatomy learning: A pilot study at the Universidad del Norte in Barranquilla, Colombia. *Anat Sci Educ*, 7(5), 399-405. doi:10.1002/ase.1444
- Mathiowetz, V., Yu, C. H., & Quake-Rapp, C. (2016). Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. *Anat Sci Educ*, 9(1), 52-59. doi:10.1002/ase.1528
- Mc Garvey, A., Hickey, A., & Conroy, R. (2015). The anatomy room: a positive learning experience for nursing students. *Nurse Educ Today*, 35(1), 245-250. doi:10.1016/j.nedt.2014.07.007

- McCulloch, C., Marango, S. P., Friedman, E. S., & Laitman, J. T. (2010). Living AnatoME: Teaching and Learning Musculoskeletal Anatomy through Yoga and Pilates. *Anat Sci Educ*, 3(6), 279-286. doi:<http://dx.doi.org/10.1002/ase>. 181
- Melovitz-Vasan, C., DeFouw, D. O., & Vasan, N. S. (2013). How do we teach anatomy? Use of team-based learning strategy. In *Education in Anatomical Sciences* (pp. 33-44)
- 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. *Ann Anat*, 218, 156-164. doi:10.1016/j.aanat.2018.02.015
- Mogali, S. R., Yeong, W. Y., Tan, H. K. J., Tan, G. J. S., Abrahams, P. H., Zary, N., . . . Ferenczi, M. A. (2018). Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. *Anat Sci Educ*, 11(1), 54-64. doi:10.1002/ase.1703
- Moro, C., Stromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anat Sci Educ*, 10(6), 549-559. doi:10.1002/ase.1696
- Morton, D. A., & Colbert-Getz, J. M. (2017). Measuring the Impact of the Flipped Anatomy Classroom: The Importance of Categorizing an Assessment by Bloom's Taxonomy. *Anat Sci Educ*, 10(2), 170-175. doi:<http://dx.doi.org/10.1002/ase>.1635

- Moscova, M., Bryce, D. A., Sindhusake, D., & Young, N. (2015). Integration of medical imaging including ultrasound into a new clinical anatomy curriculum. *Anat Sci Educ*, 8(3), 205-220. doi:10.1002/ase.1481
- Murakami, T., Tajika, Y., Ueno, H., Awata, S., Hirasawa, S., Sugimoto, M., . . . Yorifuji, H. (2014). An integrated teaching method of gross anatomy and computed tomography radiology. *Anat Sci Educ*, 7(6), 438-449. doi:10.1002/ase.1430
- Musumeci, G., Loreto, C., Mazzone, V., Szychlinska, M. A., Castrogiovanni, P., & Castorina, S. (2014). Practical training on porcine hearts enhances students' knowledge of human cardiac anatomy. *Ann Anat*, 196(2-3), 92-99. doi:10.1016/j.aanat.2014.02.002
- Naeger, D. M., Conrad, M., Nguyen, J., Kohi, M. P., & Webb, E. M. (2013). Students teaching students: evaluation of a "near-peer" teaching experience. *Acad Radiol*, 20(9), 1177-1182. doi:10.1016/j.acra.2013.04.004
- O'Reilly, M. K., Reese, S., Herlihy, T., Geoghegan, T., Cantwell, C. P., Feeney, R. N., & Jones, J. F. (2016). Fabrication and assessment of 3D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. *Anat Sci Educ*, 9(1), 71-79. doi:10.1002/ase.1538
- Oakes, D. J., Hegedus, E. M., Ollerenshaw, S. L., Drury, H., & Ritchie, H. E. (2018). Using the Jigsaw Method to Teach Abdominal Anatomy. *Anat Sci Educ*. doi:10.1002/ase.1802
- Oh, C.-S., Won, H.-S., Kim, K.-J., & Jang, D.-S. (2011). "Digit Anatomy": A New Technique for Learning Anatomy Using Motor Memory. *Anat Sci Educ*, 4(3), 132-141. doi:http://dx.doi.org/10.1002/ase.223



- Pais, D., Casal, D., Mascarenhas-Lemos, L., Barata, P., Moxham, B. J., & Goyri-O'Neill, J. (2017). Outcomes and satisfaction of two optional cadaveric dissection courses: A 3-year prospective study. *Anat Sci Educ*, *10*(2), 127-136. doi:10.1002/ase.1638
- Pan, S., Cheng, X., Zhou, Y., Li, K., & Yang, X. (2017). Seeking the Optimal Time for Integrated Curriculum in Jinan University School of Medicine. *International Journal of Higher Education*, *6*(1), 25-33.
- Park, S. E., & Howell, T. H. (2015). Implementation of a flipped classroom educational model in a predoctoral dental course. *J Dent Educ*, *79*(5), 563-570.
- Parmar, S. K., & Rathinam, B. A. D. (2011). Introduction of Vertical Integration and Case-Based Learning in Anatomy for Undergraduate Physical Therapy and Occupational Therapy Students. *Anat Sci Educ*, *4*(3), 170-173. doi:http://dx.doi.org/10.1002/ase.225
- Peeler, J., Bergen, H., & Bulow, A. (2018). Musculoskeletal Anatomy Education: Evaluating the Influence of Different Teaching and Learning Activities on Medical Students Perception and Academic Performance. *Ann Anat*, *219*, 44-50. doi:10.1016/j.aanat.2018.05.004
- Perumal, V. (2018). A sectional anatomy learning tool for medical students: development and user-usage analytics. *Surg Radiol Anat*, *40*(11), 1293-1300. doi:10.1007/s00276-018-2082-5
- Pickering, J. D. (2015). Anatomy Drawing Screencasts: Enabling Flexible Learning for Medical Students. *Anat Sci Educ*, *8*(3), 249-257. doi:http://dx.doi.org/10.1002/ase.1480

- Pickering, J. D. (2017). Measuring Learning Gain: Comparing Anatomy Drawing Screencasts and Paper-Based Resources. *Anat Sci Educ*, 10(4), 307-316. doi:<http://dx.doi.org/10.1002/ase.1666>
- Pickles, K., Ivanusic, J. J., Xiao, J., Durward, C., Ryan, A. B., & Hayes, J. A. (2019). Peer Tutoring for Anatomy Workshops in Cambodia. *Anat Sci Educ*, 12(1), 82-89. doi:10.1002/ase.1804
- Pizzimenti, M. A., Pantazis, N., Sandra, A., Hoffmann, D. S., Lench, S., & Ferguson, K. J. (2016). Dissection and dissection-associated required experiences improve student performance in gross anatomy: Differences among quartiles. *Anat Sci Educ*, 9(3), 238-246. doi:10.1002/ase.1574
- Pujol, S., Baldwin, M., Nassiri, J., Kikinis, R., & Shaffer, K. (2016). Using 3D Modeling Techniques to Enhance Teaching of Difficult Anatomical Concepts. *Acad Radiol*, 23(4), 507-516. doi:10.1016/j.acra.2015.12.012
- Ramsey-Stewart, G., Burgess, A. W., & Hill, D. A. (2010). Back to the future: teaching anatomy by whole-body dissection. *Med J Aust*, 193(11-12), 668-671.
- Rea, P., & Linn, A. (2017). Creation of E-tutorials to enhance medical student anatomy learning experience using articulate storyline 2. In *Serious Games and Edutainment Applications: Volume II* (pp. 203-221)
- Reilly, F. D. (2011). Outcomes from Building System Courseware for Teaching and Testing in a Discipline-Based Human Structure Curriculum. *Anat Sci Educ*, 4(4), 190-194. doi:<http://dx.doi.org/10.1002/ase.227>
- Rempell, J. S., Saldana, F., DiSalvo, D., Kumar, N., Stone, M. B., Chan, W., . . . Kohler, M. J. (2016). Pilot Point-of-Care Ultrasound Curriculum at Harvard

Medical School: Early Experience. *West J Emerg Med*, 17(6), 734-740. doi: 10.5811/westjem.2016.8.31387

Resuehr, D., & Makeeva, V. (2015). Development of a Flexible, Co-enrolled Teaching Assistant Program in an Anatomy Course with a Low Faculty-to-Student Ratio. *Med Sci Educ*, 25(1), 53-60. doi:10.1007/s40670-014-0099-x

Rich, P., & Guy, R. (2013). A "Do-It-Yourself" Interactive Bone Structure Module: Development and Evaluation of an Online Teaching Resource. *Anat Sci Educ*, 6(2), 107-113. doi:http://dx.doi.org/10.1002/ase.1312

Richardson-Hatcher, A., Hazzard, M., & Ramirez-Yanez, G. (2014). The cranial nerve skywalk: A 3D tutorial of cranial nerves in a virtual platform. *Anat Sci Educ*, 7(6), 469-478. doi:10.1002/ase.1445

Saalu, L. C., Abraham, A. A., & Aina, W. O. (2010). Quantitative evaluation of third year medical students' perception and satisfaction from problem based learning in anatomy: A pilot study of the introduction of problem based learning into the traditional didactic medical curriculum in Nigeria. *Educational Research and Reviews*, 5(4), 193-200.

Serrao, G., Tassoni, M., Magenta-Biasina, A. M., Mantero, A. G., Previtera, A., Turci, M. C., . . . Bertolini, E. A. M. (2017). Virtual Dissection by Ultrasound: Probe Handling in the First Year of Medical Education. *Ultrasound Int Open*, 3(4), E156-e162. doi:10.1055/s-0043-121983

Serrat, M. A., Dom, A. M., Buchanan, J. T., Jr., Williams, A. R., Efaw, M. L., & Richardson, L. L. (2014). Independent learning modules enhance student performance and understanding of anatomy. *Anat Sci Educ*, 7(5), 406-416. doi:10.1002/ase.1438

- Shaffer, J. F. (2016). Student performance in and perceptions of a high structure undergraduate human anatomy course. *Anat Sci Educ*, 9(6), 516-528. doi:10.1002/ase.1608
- Siqueira Da Silva, I. C., Klein, G., & Brandao, D. M. (2017). *Segmented and detailed visualization of anatomical structures for health education*. Paper presented at the Proceedings - International Conference of the Chilean Computer Science Society, SCCC
- Smith, C. F., Tollemache, N., Covill, D., & Johnston, M. (2018). Take away body parts! An investigation into the use of 3D-printed anatomical models in undergraduate anatomy education. *Anat Sci Educ*, 11(1), 44-53. doi:10.1002/ase.1718
- Smith, J. P., Kendall, J. L., & Royer, D. F. (2018). Improved medical student perception of ultrasound using a paired anatomy teaching assistant and clinician teaching model. *Anat Sci Educ*, 11(2), 175-184. doi:10.1002/ase.1722
- Stewart, S., & Choudhury, B. (2015). Mobile technology: Creation and use of an iBook to teach the anatomy of the brachial plexus. *Anat Sci Educ*, 8(5), 429-437. doi:10.1002/ase.1501
- Stirling, A., & Birt, J. (2014). An enriched multimedia eBook application to facilitate learning of anatomy. *Anat Sci Educ*, 7(1), 19-27. doi:10.1002/ase.1373
- Sweetman, G. M., Crawford, G., Hird, K., & Fear, M. W. (2013). The benefits and limitations of using ultrasonography to supplement anatomical understanding. *Anat Sci Educ*, 6(3), 141-148. doi:10.1002/ase.1327
- Swinnerton, B. J., Morris, N. P., Hotchkiss, S., & Pickering, J. D. (2017). The integration of an anatomy massive open online course (MOOC) into a

medical anatomy curriculum. *Anat Sci Educ*, 10(1), 53-67. doi:10.1002/ase.1625

Sytsma, T. T., Haller, E. P., Youdas, J. W., Krause, D. A., Hellyer, N. J., Pawlina, W., & Lachman, N. (2015). Long-term effect of a short interprofessional education interaction between medical and physical therapy students. *Anat Sci Educ*, 8(4), 317-323. doi:10.1002/ase.1546

ten Brinke, B., Klitsie, P. J., Timman, R., Busschbach, J. J., Lange, J. F., & Kleinrensink, G. J. (2014). Anatomy education and classroom versus laparoscopic dissection-based training: a randomized study at one medical school. *Acad Med*, 89(5), 806-810. doi:10.1097/acm.0000000000000223

Thomas, K. J., Denham, B. E., & Dinolfo, J. D. (2011). Perceptions among Occupational and Physical Therapy Students of a Nontraditional Methodology for Teaching Laboratory Gross Anatomy. *Anat Sci Educ*, 4(2), 71-77. doi:http://dx.doi.org/10.1002/ase.208

Thomas, R. G., John, N. W., & Delieu, J. M. (2010). Augmented reality for anatomical education. *J Vis Commun Med*, 33(1), 6-15. doi:10.3109/17453050903557359

Topping, D. B. (2014). Gross Anatomy Videos: Student Satisfaction, Usage, and Effect on Student Performance in a Condensed Curriculum. *Anat Sci Educ*, 7(4), 273-279. doi:http://dx.doi.org/10.1002/ase.1405

Torres, A., Staskiewicz, G. J., Lisiecka, J., Pietrzyk, L., Czekajlo, M., Arancibia, C. U., . . . Torres, K. (2016). Bridging the gap between basic and clinical sciences: A description of a radiological anatomy course. *Anat Sci Educ*, 9(3), 295-303. doi:10.1002/ase.1577

- Van Nuland, S. E., & Rogers, K. A. (2017). The skeletons in our closet: E-learning tools and what happens when one side does not fit all. *Anat Sci Educ*, 10(6), 570-588. doi:10.1002/ase.1708
- Wang, J., Zhang, W., Qin, L., Zhao, J., Zhang, S., Gu, J., & Zhou, C. (2010). Problem-Based Learning in Regional Anatomy Education at Peking University. *Anat Sci Educ*, 3(3), 121-126. doi:http://dx.doi.org/10.1002/ase.151
- Waters, J. R., Van Meter, P., Perrotti, W., Drogo, S., & Cyr, R. J. (2011). Human Clay Models versus Cat Dissection: How the Similarity between the Classroom and the Exam Affects Student Performance. *Adv Physiol Educ*, 35(2), 227-236. doi:http://dx.doi.org/10.1152/advan.00030.2009
- Wilkinson, K., & Barter, P. (2015). Do Mobile Learning Devices Enhance Learning in Higher Education Anatomy Classrooms? In (pp. 1-8): International Association for the Development of the Information Society
- Williams, S. R., Thompson, K. L., Notebaert, A. J., & Sinning, A. R. (2019). Prosection or Dissection: Which is Best for Teaching the Anatomy of the Hand and Foot? *Anat Sci Educ*, 12(2), 173-180. doi:10.1002/ase.1808
- Wright, S. J. (2012). Student perceptions of an upper-level, undergraduate human anatomy laboratory course without cadavers. *Anat Sci Educ*, 5(3), 146-157. doi:10.1002/ase.1265
- Wu, A. M., Wang, K., Wang, J. S., Chen, C. H., Yang, X. D., Ni, W. F., & Hu, Y. Z. (2018). The addition of 3D printed models to enhance the teaching and learning of bone spatial anatomy and fractures for undergraduate students: a randomized controlled study. *Ann Transl Med*, 6(20), 403. doi:10.21037/atm.2018.09.59

Yeom, S., Choi-Lundberg, D., Fluck, A., & Sale, A. (2013). *User Acceptance of a Haptic Interface for Learning Anatomy.*

Yi, X., Ding, C., Xu, H., Huang, T., Kang, D., & Wang, D. (2019). Three-Dimensional Printed Models in Anatomy Education of the Ventricular System: A Randomized Controlled Study. *World Neurosurg.* doi:10.1016/j.wneu.2019.01.204

Zumwalt, A. C., Lufler, R. S., Monteiro, J., & Shaffer, K. (2010). Building the Body: Active Learning Laboratories that Emphasize Practical Aspects of Anatomy and Integration with Radiology. *Anat Sci Educ*, 3(3), 134-140. doi:http://dx.doi.org/10.1002/ase.153

# Curriculum Vitae

Name	alex wolf
Post Secondary Education and Degrees	B.HSc, Western University
Awards	Health Studies Award of Recognition (2017)
Related Work Experience	Teaching Assistant: HS 2300A/B (2017-2018) Teaching Assistant: HS 3300B (2019)