# THREE-DIMENSIONAL VISUALIZATION TECHNOLOGY IN THE MEDICAL CURRICULUM: EXPLORING FACULTY USE IN PRECLINICAL, CLINICAL, AND POSTGRADUATE ANATOMY EDUCATION

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# DEDICATION

I dedicate this dissertation to my father whose love of life has always inspired me and whose endless support and encouragement has helped me thrive, even in the toughest of times. Thank you for always demonstrating the value of hard work, and the importance of family, generosity, and humility. I would not be who I am today without you, and I am forever thankful to have you as a father.

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Background: The advancement of three-dimensional visualization technology provides exciting new opportunities in medical education, including new methods for teaching complex anatomical relationships and promising tools for the training of postgraduate physicians. Information on how faculty use three-dimensional visualization technology for anatomy education is essential for informed discussions surrounding their effectiveness as a teaching tool and use in the medical curriculum, yet the current literature lacks necessary contextual details on how faculty integrate these technologies into actual medical curricula.

Methods: Fifteen medical educators from North American medical schools and teaching hospitals completed semi-structured interviews and discussed how they use three-dimensional visualization technology for teaching in preclinical courses, clinical clerkships, and postgraduate programs. Transcripts were analyzed using the constant comparative method and resulting themes were used to inform the creation of a questionnaire.

Results: The resulting themes of analysis were organized according to a curricular framework that describes how faculty use these technologies as an instructional resource and how this use is related to the purposes, content, sequence, instructional processes and evaluation of medical curricula. The results demonstrate how three-dimensional visualization technology is being is implemented in a variety of ways in the curriculum and revealed numerous similarities of use across the levels of medical education. Analyses revealed minimal use of three-dimensional visualization technology for assessment and indicated faculty face significant challenges in designing such assessment.

Conclusions: Results suggest continuing assessment of the effectiveness of these technologies as a teaching tool needs to encompass broader aspects of use, such as those described in this study. Additionally, results showing similarities of use across levels suggest that educators and administrators should consider how three-dimensional visualization technology can be thoughtfully integrated to address the changing needs of learners as they progress through medical education. Findings also suggest that administrators who want to support the integration of three-dimensional visualization technology into the curriculum need to provide adequate support and training to help faculty overcome time limitations and difficulties designing assessment methods.

Laura J. Torbeck, Ph.D., Chair

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# CHAPTER 1: INTRODUCTION

The advancement of three-dimensional (3D) technology provides exciting new opportunities in health care and medical education, particularly in the field of anatomy. Medical educators use a wide variety of technologies that provide computer generated 3D visualizations of the human body. These 3D visualization technologies (3DVTs) offer new methods for teaching complex anatomical relationships and promising tools for the training of postgraduate physicians (Hackett and Proctor, 2016). Anatomy is often described as a cornerstone of medical education, and anatomical knowledge acquired during preclinical years is subsequently built upon through clinical clerkships and postgraduate residency training. A strong understanding of the complex spatial relationships of human structure is central to the clinical practice of physicians, and deficiencies of knowledge may translate to poor patient care (Marks Jr, 2000; Ellis, 2002). If the use of 3DVTs in medical education has the potential to improve understanding of the anatomical spatial relationships that are fundamental to patient care, the role it plays in the medical curriculum is worthy of exploration.

In traditional medical curricula students first encounter anatomy during their basic science coursework that makes up the pre-clinical years of medical education. In North American medical schools the first one to two years of undergraduate medical education (UME) constitute the pre-clinical portion of the curriculum; the associated coursework includes some combination of the four anatomical subdisciplines: gross anatomy, histology, neuroanatomy, and embryology (Prentice, 2013). In this initial phase students not only learn the nomenclature and identification of fundamental human structures, but they also begin to develop their 3D understanding of anatomical relationships, traditionally through exposure to cadaveric dissection (Turney, 2007).

Students' understanding of anatomy is further developed during the clinical phase of UME and subsequently mastered during postgraduate residencies. In North America the third and fourth years of UME are considered clinical years during which students typically complete various required and elective clerkship and sub-internship rotations through a variety of medical specialties. Following graduation from medical school, postgraduate training consists of a clinical residency which ranges from three to seven years depending on the specialty (Prentice, 2013). Clinical anatomy is emphasized during undergraduate clerkships and postgraduate residency programs, particularly in specialties such as surgery, radiology, and obstetrics and gynecology (OB-GYN). In these specialties, where anatomical knowledge is fundamental to patient care, it is essential that residents master the complex spatial relationships of human structure.

While anatomy learned during the preclinical phase sets the foundation for the knowledge needed to practice medicine, an increasingly crowded curriculum has reduced the contact hours available for teaching and dissection, leading to concerns about deficiencies in postgraduates' anatomical knowledge (Marks Jr, 2000). Multiple studies have shown that several groups, including students, clinicians, and program directors, have concerns regarding the adequacy of anatomy teaching in medical education (Waterston and Stewart, 2005; Fitzgerald et al., 2008; Bhangu et al., 2010; Fillmore et al., 2016). Results of a survey done by Cottam (1999) revealed that over twothirds of residency program directors believed the anatomy preparation of new residents was inadequate.

Medical educators are concerned about the impact of the potentially suboptimal anatomy education in health care. In his review regarding the status of anatomy knowledge, Yammine (2014) stresses “an inadequate knowledge of the structure can affect the future understanding of the function, the dysfunction, and eventually the knowledge and skills of the therapeutic modalities” (p. 185). The reported increases of medico-legal claims related to anatomical errors, such as ‘damage to underlying structures’, appears to support these concerns about the consequences of gaps in students’ anatomical knowledge (Ellis, 2002).

In the ongoing discussion of solutions for addressing deficiencies in anatomical knowledge, several people have pointed out the potential for the use of 3DVT in anatomy education to promote knowledge retention, improve spatial understanding, and increase exposure to clinical applications of anatomy (Inuwa et al., 2012; Yammine, 2014; Hackett and Proctor, 2016). Nicholson et al. (2006) emphasize the value of using 3DVT to teach small, complex structures, such as the inner ear which may be difficult to visualize during dissection. In their discussion of augmented reality, Kamphuis et al. (2014) discuss the possibility of using virtual content to offer safe training environments where trainees can practice real-world tasks. Additionally, in programs where dissection time may be limited, 3DVT may offer realistic visualizations of anatomical structures, providing students an opportunity to enhance their learning of complex spatial relationships (McLachlan et al., 2004).

There are numerous studies that have examined the effectiveness of 3DVT in anatomy education, including how it impacts student learning and satisfaction. Rengier et al. (2009) reported positive student evaluations of a virtual anatomy program they integrated into their radiology lessons, and found that students believed the 3D images aided in their understanding. Yammine and Violato (2014) conducted a meta-analysis to examine the effectiveness of 3DVTs compared to traditional teaching methods, such as lectures and textbooks containing two-dimensional (2D) images. Their analysis of 36 studies found promise in the usefulness of 3DVT for teaching anatomy, including improvements in spatial and factual knowledge and higher levels of student satisfaction compared to other teaching methods. Finally, Hackett and Proctor (2016) report that 74% of the articles they reviewed found beneficial results of 3DVT use in anatomical education settings.

While much of the recent research shows promise for the effectiveness of 3DVT as a teaching tool, some results offer less than positive findings. Hackett and Proctor (2016) found that 16% of the studies they reviewed obtained mixed results, while 10% reported no positive effect due to 3DVT use. For example in a randomized controlled study, Metzler et al. (2012) found no significant difference between the 2D and 3D trained groups in correct interpretation of 2D medical imaging. Similarly, multiple studies found that while students preferred using computer generated 3D models over textbook materials to learn anatomy of the liver (Keedy et al., 2011), larynx (Hu et al., 2010; Tan et al., 2012) and cranial nerves (Yeung et al., 2012), there was no significant difference in performance between groups. Possible explanations for these mixed results include variations in study design such as sample size, level of interactivity, and length of the intervention (Nicholson et al., 2006). Other explanations highlight specific curricular elements, such as student backgrounds, learning environments, and instructional methods, which may play a role in determining the effectiveness of 3DVT (Hoyek et al., 2014; Peterson and Mlynarczyk, 2016). Thus, discussions regarding the effectiveness of 3DVT in anatomy education should include careful consideration of how its integration in the curriculum may impact results.

Furthermore, discussions of curricular design involving 3DVT use should be informed by a thorough understanding of faculty experiences and perceptions. Faculty make important decisions regarding the curriculum and their experience of 3DVT use in anatomy education is an important consideration. In his discussion of change theory, Fullan (1982) highlights the importance of faculty experiences stating, "educational change depends on what teachers do and think – it's as simple and complex as that" (p. 107). Additionally, Groff and Mouza (2008) identify teachers as one of the six critical factors that influence the implementation of technology in the classroom. Ultimately the use of technology is highly dependent on the perceptions of the teachers who use it and understanding faculty experiences of 3DVT use is required for meaningful discussions of curricular assessment and reform (Mumtaz, 2000).

**Problem Statement**

Students are expected to develop a foundational understanding of anatomy during preclinical coursework, and subsequently build their understanding of the complex spatial relationships of the human body through clinical clerkships and postgraduate residencies. Yet, there is concern regarding the level of anatomy knowledge that postgraduate medical students possess and how this could impact the level of care patients receive (Marks Jr, 2000; Yammine, 2014). Many looking to improve anatomy education in the medical curriculum have turned to 3DVT as a teaching tool due to its potential to enhance understanding of spatial relationships, increase student interest, and contribute clinically relevant content. Research shows promise in the effectiveness of 3DVT use for anatomy education; but some uncertainty indicates further evaluation of effectiveness is needed (Hackett and Proctor, 2016).

Further assessment of 3DVT effectiveness and discussions surrounding its role in anatomy education reform need to be informed by an understanding of how faculty are using 3DVT in the medical curriculum. Faculty play an important role in the integration of technology in the medical curriculum, and as Bitner and Bitner (2002) indicate, "before technology can effect changes in the classroom, those ultimately responsible for the classroom must be considered" (p. 95). In other words, before purposeful assessment and integration of 3DVT can occur, evidence is needed regarding the different ways in which basic science, clinical, and postgraduate faculty use 3DVT for anatomy education within the medical curriculum. However, no framework exists to explain how faculty purposefully integrate 3DVT into the medical curriculum, and past research has not identified the key variables needed to characterize differences in 3DVT use.

**Purpose of the Study**

While research concerning the use of 3DVT in medical education has centered on assessing effectiveness, evidence related to the specific ways in which faculty use such technologies within the curriculum is needed. In order to address the gap in the literature, the aim of this study was to describe and compare how faculty use 3DVT for anatomy education in the preclinical, clinical, and postgraduate medical curricula. Understanding how faculty approach using 3DVT in anatomy education will provide a framework for more productive discussions of 3DVT assessment and integration within the medical curriculum. Examination of the different approaches to using 3DVT could help shed light on the reasons behind the successes or failures of their use as a teaching tool. Additionally, a deeper understanding of the different ways in which preclinical, clinical, and postgraduate faculty approach 3DVT use will help facilitate conversations and inform curriculum reform. Yammine (2014) suggests that the challenges of integrating modern methods in the curriculum can be facilitated through communication between clinicians and academics to better align their perspectives.

With a better understanding of 3DVT use across all levels of medical education, policy makers, administrators, and faculty will be better equipped to make informed decisions about future directions to take. Ideally, this understanding will allow 3DVT to be more effectively integrated into medical education and better address deficiencies in anatomical knowledge. A strong understanding of anatomy provides the foundation of health care. Therefore, increasing medical graduates’ knowledge of complex spatial relationships of the human body is an important goal of medical education; one that may lead to improvements in the level of care patients receive (Marks Jr, 2000).

**Theoretical Framework**

To effectively examine how faculty use 3DVT for anatomy education in the medical curriculum, a guiding definition of curriculum is needed. Definitions of curriculum vary widely among academics, and faculty definitions often oversimplify the complexities of a curriculum (Burton and McDonald, 2001). Vague or inconsistent definitions of curriculum can hinder the ability to have informed and productive discussions about specific components which may be important for consideration (Lattuca and Stark, 2011). In order to provide a framework for productive discussions about curriculum, Lattuca and Stark (2011) propose the concept of defining curriculum as an academic plan, which consists of 8 major elements a curriculum must address:

1. PURPOSES: knowledge, skills, and attitudes to be learned
2. CONTENT: subject matter selected to convey specific knowledge, skills, and attitudes
3. SEQUENCE: an arrangement of the subject matter and experiences intended to lead to specific outcomes for learners
4. LEARNERS: how the plan will address a specific group of learners
5. INSTRUCTIONAL PROCESSES: the instructional activities by which learning may be achieved
6. INSTRUCTIONAL RESOURCES: the materials and settings to be used in the learning process
7. EVALUATION: the strategies used to determine whether decisions about the elements of the academic plan are optimal
8. ADJUSTMENT**:** enhancements to the plan based on experience and evaluation (p. 4).

The topics explored in this dissertation related to 3DVT use for anatomy education within the medical curriculum were examined via this definitional framework of the curriculum as an academic plan. This framework was selected because these elements can be considered at all levels of a curriculum, and represent critical decision points in the design of effective academic experiences (Lattuca and Stark, 2011). This allows the framework to be used to explore relevant components of the medical curriculum specific to anatomy education.

The academic plan model was used to focus the research questions on elements which represent potential intervention points, so that insights gained from the study can be easily incorporated into meaningful discussions of curricular reform. Because 3DVT is used by faculty as a material in the learning process it can be framed as an instructional resource. Thus, the research questions for this study examined the use of 3DVT as an instructional resource, as well as its use as a resource in relation to other academic plan elements: purposes, content, sequence, instructional processes, and evaluation. The remaining elements, adjustment and learners, were determined to be outside the scope of this study because they represent a separate process and an individual group which are large enough to necessitate studies of their own.

## Research Questions

The importance of 3DVT in medical education and the lack of information regarding its role in the current curriculum suggests that it needs to be studied in a more intentional manner. While many studies have examined the effectiveness of 3DVT, no studies have explored specific ways faculty use 3DVT in the medical curriculum or how this use differs at various levels of medical education. Therefore, this study investigated (a) how faculty use 3DVT for anatomy education in the medical curriculum and (b) how this use differs among preclinical, clinical, and postgraduate faculty. Based on the perceptions of the participants in this study, the following research questions were addressed:

1) In what ways do faculty use 3DVT for anatomy education within the preclinical, clinical, and postgraduate medical curriculum?

    Sub-questions (a-f) are framed according to Lattuca and Stark's (2011) academic plan model:

    a. How do faculty use 3DVT as an instructional resource?
    b. What do faculty see as the purpose of anatomy education at their respective level and how do they use 3DVT to try to achieve these goals?
    c. What content is taught using 3DVT, and what knowledge, skills, and attitudes are faculty trying to convey?
    d. How do faculty arrange the subject matter and learning experiences associated with 3DVT use? How is sequence used to try to achieve desired learning outcomes?
    e. Into what type of instructional processes are 3DVTs incorporated?
    f. How are 3DVTs used to evaluate student learning?

2) What similarities and differences exist in how faculty use 3DVT for anatomy education in the preclinical, clinical, and postgraduate medical curriculum?

## Overview of Research Methodology

The research questions in this study were answered using a qualitative approach to data collection and analysis. The use of qualitative methods allowed for the creation of a framework for 3DVT use that is grounded in the experiences of faculty participants. The use of 3DVT in the medical curriculum was examined using one-on-one, semi structured interviews with faculty members who use 3DVT as a teaching tool in preclinical anatomy courses, clerkships rotations, and/or residency programs, within North American medical schools. Participants were asked to talk about the educational goals of their programs and their experiences integrating the use of 3DVT into the curriculum including the timing of 3DVT use, learning activities utilizing 3DVT, and assessment of student learning. Finally, the themes generated from this initial qualitative exploration were used to create items for a questionnaire which will allow future research to quantitatively examine the use of 3DVT in medical education.

## Overview of the Dissertation

Chapter two of this dissertation reviews the relevant literature on anatomy education in medical curriculum, followed by the use and assessment of 3DVT in medical education. Chapter three details the research methodology including participant descriptions, data collection and analysis methods, and methods used for questionnaire creation. Chapter four presents the results of the qualitative data analysis of faculty interviews, and a description of how the qualitative themes informed questionnaire items. Finally, chapter five provides a discussion of the results.

# CHAPTER 2: REVIEW OF THE LITERATURE

## Anatomy Education in the Medical Curriculum

The anatomical sciences have long been a part of medical education, and they can be found integrated throughout the medical curriculum from the first year of preclinical coursework to postgraduate training. Much of the medical curriculum is designed to ensure doctors have sufficient knowledge to perform physical examinations, as well as diagnostic and therapeutic procedures. Knowledge of the four anatomical subdisciplines, gross anatomy, histology, neurology, and embryology, provides an important foundation for these clinical skills required for sound medical practice (Leonard, 1996; Smith and Mathias, 2011). Though there is wide variability in the curriculum of medical schools, anatomy education of some form is typically found in each of the preclinical, clinical, and postgraduate levels of medical education.

Many North American medical schools still use a traditional four-year curriculum, in which the first two years of UME consists predominantly of basic science course work. Most medical schools adopted this type of curriculum after the release of the Flexner report (1910), in which education expert, Abraham Flexner, stressed the need for separating basic science teaching and clinical training (Duffy, 2011). In this traditional curriculum the bulk of anatomy education occurs in the preclinical years and focuses on providing students with foundational knowledge applicable to all areas of medical practice, but often does not provide the in-depth clinical anatomy necessary for specialized training (Lisk et al., 2014). While there has been much debate on the best method for teaching anatomy, didactic lectures and cadaveric dissection have been the primary methods used for centuries. Other resources used for anatomy education include living anatomy in the form of surface anatomy or ultrasound, study of prosections or models, computer based learning, and medical imaging (Estai and Bunt, 2016).

More recently, an expansion of scientific knowledge and concerns regarding the effectiveness of medical education have driven widespread curricular reform, changing the format of preclinical anatomy education in many medical schools. Scientific research has grown the knowledge base which must be acquired for modern medical practice, resulting in an increasingly crowded curriculum. Additionally, much debate surrounds the effectiveness of medical education in preparing junior doctors for the challenges of applying basic science knowledge to clinical practice (Turney, 2007). Changes made in response to these growing concerns have included the integration of clinical content into basic science coursework, the increase of problem-based learning, the reduction of total hours devoted to anatomy teaching, and the integration of multiple disciplines into systems-based blocks (Spencer et al., 2008; Drake et al., 2009; Louw et al., 2009).

Of these changes, integration is one of the most widely discussed, with many North American medical schools implementing varying levels of integration in their curriculum (Loftus, 2015). Integration can include horizontal integration, tying together different subject areas, or vertical integration that combines basic science with clinical topics. Integration may be as simple as teaching the anatomy and physiology of systems simultaneously, or as complex as integrating a variety of subjects into a single clinical scenario, such that clinical aspects are tied to multiple areas such as anatomy, cell biology, pharmacology, ethics, etc. Proponents of integration argue that it is necessary for helping medical students learn problem-solving skills and developing their ability to apply knowledge learned (Bandiera et al., 2013).

As students enter the clinical portion of UME the focus shifts from obtaining basic science knowledge, to the clinical application of this knowledge during clerkship and sub-internship rotations. Anatomy education is less extensive during the third- and fourth- years, but many schools still include some type of anatomy focused experiences to help students gain a deeper understanding of anatomy. According to a review of medical school curricula by Spencer et al. (2008), only 19% of US schools and 24% of Canadian schools included basic science courses during the clinical years. These courses averaged just 4 weeks in duration, were unlikely to focus on anatomy alone, and varied from didactic lectures to integrative case studies with laboratory experiences (Spencer et al., 2008).

Despite sparse basic science courses, students at many programs are exposed to additional experiences in anatomy during their clinical years through participation in near-peer teaching. For example, Mayo Clinic senior students participating in the Student-as-Teacher program assist teaching gross anatomy in the Surgical First Assistant program, allowing them to "further explore and teach material regarding their surgical area of interest" (Heidenreich et al., 2016, p. 99) . While many of these programs are created to add teaching assistants to the preclinical course labs, or help senior students refine their teaching and leadership skills, it may also serve as an opportunity for them to gain a deeper understanding of anatomy. Evans and Cuffe (2009) report near-peer teaching led to deeper learning of anatomy, however this conclusion was based on students' self-reported improvements in knowledge and understanding, which may not reflect an accurate estimation of knowledge gains.

Postgraduate medical education is defined by the World Federation for Medical Education (2015) as, "the phase in which doctors develop competencies under supervision towards independent practice after completion of their basic medical qualification" (p. 15). Postgraduate education primarily involves completion of a residency program that provides specialized training in a selected field and may also include completion a fellowship program in a specific subspecialty. In the US the required competencies that residents and fellows in these programs are expected to master are set by the Accreditation Council for Graduate Medical Education (ACGME). Each program designs their curriculum to achieve the competencies specific to their field, leading to a large variation in the curricula of postgraduate training programs (Weggemans et al., 2017).

There has been little published on the specific curricular designs of postgraduate training programs and while anatomical knowledge forms the foundation of specialties such as surgery, radiology, and OB-GYN, there is even less empirical research that focuses on anatomy education within these specialties. In their discussion of radiology education Cohen et al. (2005) explain that, "traditionally, radiology residents learned by serving an apprenticeship in the clinical environment (the reading room) and through didactic venues (i.e., lectures)" (p. 647). Radiology residency programs also commonly include problem-based learning in what are known as conferences, where groups of students and staff review and discuss clinical cases. Similarly, surgical residents typically revisit anatomy through reading material and lectures, as well as through instruction from senior surgeons in the operating room (Corton et al., 2003). Additionally, some residents are able to review basic anatomy through co-teaching opportunities in undergraduate medical courses (Lee et al., 1999).

Recently there has been concern regarding how graduate student understanding of anatomy is influenced by factors such as the reduction in time devoted to anatomy teaching, the expanse of time between basic science courses and postgraduate education, the reduced use of cadavers at some schools, and the drastically changing structure of the medical curriculum (Marks Jr, 2000; Turney, 2007; Lisk et al., 2014; Yammine, 2014). While empirical evidence supporting these concerns is limited, there is nevertheless many program directors who feel their incoming residents lack necessary anatomical knowledge (Cottam, 1999; Bergman et al., 2011; Fillmore et al., 2016). Additionally, while residents learning from senior surgeons is an invaluable educational tool, time constraints and concerns surrounding patient safety can limit opportunities for extensive review of anatomy during operations (Corton et al., 2003).

To ensure residents achieve the level of understanding necessary for clinical practice many programs have implemented structured anatomy courses to supplement more traditional experiences. These programs have been used in a variety of postgraduate specialties including Emergency Medicine (Hamilton and Nagy, 1985), Gynecologic and Radiation Oncology (Barton et al., 2009; Labranche et al., 2015), Physical Medicine and Rehabilitation (Lisk et al., 2014), and Orthopedic Surgery (DeFriez et al., 2011). These courses typically include a large laboratory component that provides residents time for cadaver dissection, prosection reviews, or laparoscopic dissection focused on regions relevant to the given specialty (Cundiff et al., 2001). Radiology and clinical case reviews are also integrated into many of these anatomy courses and allow students to practice application of the knowledge to which they are exposed (Hamilton and Nagy, 1985; Chino et al., 2011; Lisk et al., 2014). Overall these types of programs have been well-received by residents and have been found to improve residents understanding of anatomy (Gordinier et al., 1995; Barton et al., 2009; Labranche et al., 2015).

**Use of 3D Technology in Medical Education**

A strong clinical understanding of anatomy requires learning the many complex spatial relationships of the human body, and cadaveric dissection has long been the method used to help medical students gain a 3D understanding of anatomy. Proponents of cadaver use in medical education point to the benefits of dissection experiences such as helping students cope with death and dying, aiding in professional development, and exposing students to anatomical variability (Aziz et al., 2002; Korf et al., 2008; Ghosh, 2017; Flack and Nicholson, 2018). However, a number of concerns regarding cadaveric dissection have also been discussed, such as the ethical and moral dilemmas surrounding donor use, the impact of dissection on student’s psychological health, and the unrealistic nature of preserved tissues (Aziz et al., 2002; Bernhardt et al., 2012). Additionally, the time, faculty, and resources required to maintain a cadaveric lab can be extensive, and often prohibitive. Such concerns have led a small number of schools to significantly reduce or eliminate the use of cadavers (McLachlan et al., 2004; Ghosh, 2017; Memon, 2018).

While cadavers remain the primary method for helping students develop their 3D understanding of human structure, the recent advances of 3D visualization technology (3DVT) have provided new possibilities for teaching complex anatomical relationships. Visualization technology (VT) utilizes computer modelling to bring a visual dimension (2 or 3D) to a physical object, allowing it to be seen even when it is not physically there (Gedda, 2015). According to Yammine and Violato (2015), "3DVT in anatomy teaching includes 3D static images or photos, 3D animation, 3D movies, 3D interactive programs with controls to peel back tissue and bone revealing previously hidden layers, and 3D learning environments such as virtual reality" (p. 526).

Some have suggested that 3DVT has the potential to enhance medical education through advanced means of teaching spatial relationships, and further integration of clinically relevant content earlier into the anatomy curriculum (Yammine & Violato, 2015; Turney, 2007). Similarly, 3DVT is advancing the specialty training of postgraduate physicians in areas such as radiology, surgery, and emergency care (Marks Jr, 2000). Additionally, it is possible that future physicians could benefit from experience with 3DVT during their education since these technologies are increasingly being used for modernized methods of diagnosis, innovative approaches for treatment, and new means of patient education (Ghanbarzadeh et al., 2014; Paganelli et al., 2018).

The following sections review published literature on how 3DVT has been used for anatomy education in the medical curriculum. The goal here is not to provide a comprehensive overview of all available and described technologies, as such reviews exist elsewhere (Hansen, 2008; Kamphuis et al., 2014; Hackett and Proctor, 2016). Instead this discussion highlights the potential of 3DVT to provide new means for teaching complex spatial relationships, increase the integration of clinical content, and provide innovative training methods for postgraduate education programs.

*New Methods for Teaching Spatial Relationships*

While a growing knowledge base has increased the content taught in the medical curriculum and reduced the amount of time available for anatomy teaching, educators are still responsible for helping students build and operate within complex mental models of human structure (Estevez et al., 2010). Physicians without a rich 3D understanding of anatomy may not be prepared to safely and effectively practice medicine, where they must interpret 2D sectional images that have been obtained from 3D objects or quickly assess the risk of damage to surrounding structures during invasive procedures (Marks Jr, 2000). Estevez et al. (2010) point out that traditional teaching techniques, like the use of 2D cross-sections for teaching neuroanatomy, were "sufficient when adequate time to internalize and transform this information into 3D understanding was coupled with multiple exposures to patient and laboratory materials in the clinical years" (p. 210). Educators looking to ensure students obtain a sufficient level anatomical knowledge in the face of reduced contact hours, are advocating for new teaching methods, like 3DVT, that encourage student interest, improve the understanding and retention of knowledge, and replace theoretical-passive learning with more active-authentic experiences (Inuwa et al., 2012).

The use of computers to create 3D visualizations gives the designer an ability to add certain functionalities which increase user access to new spatial understandings not easily attained from static 2D images. The ability to add interactive controls to rotate, invert, and/or move around viewed structures allows the user to view various anatomical spatial relationships from multiple view points and angles (Yammine and Violato, 2015). For example, Trelease and Rosset (2008) created a “virtual atlas” by using imaging processing software that renders volumetric 3D images from CT and MR imaging data sets. The head and neck model in this atlas allowed students to freely rotate a 3D volume rendered head CT. The students were able to select between superficial and deep views, and the image included identifying labels that would appear when structures came into view. The “virtual atlas” also included a freely rotating 3D model of the brachiocephalic arterial trees, which allowed students to test their understanding by having them locate and name the occluded major artery (Trelease and Rosset, 2008). The interactivity of such models not only provides access to multiple viewpoints, but the use of CT data provides authentic experiences with real patient data.

Additional functions such as adjusting the transparency of tissues or highlighting specific structures to remove from view allow even further opportunities for the user to gain an appreciation of the relationships between various structures. Friedl et al. (2002) created a 3D model of the heart that not only allowed users to rotate, zoom, and fly through the image, but also view the coronary arteries with or without nearby cardiac structures. Controls also gave users the option to view the heart while beating, so that structures could be explored during different phases of the cardiac cycle. Finally, a transparency mode allowed users to visualize the relative orientation of the valves, and view active demonstrations of hemodynamics (Friedl et al., 2002). These types of 3D models create active learning experiences that engage students with the use of interactive controls. Furthermore, these materials can be stored online to allow for easy accessibility both at home and in the classroom or lab.

*Integration of Clinically Relevant Content*

While undergraduate medical education is traditionally divided into preclinical and clinical phases, there is a movement toward increasing vertical integration of the curriculum by including more clinically relevant content in early anatomy courses. Many people feel that preclinical anatomy education needs to go beyond simply teaching factual knowledge, to providing students with opportunities to practice applying their knowledge in real life scenarios. In his discussion of modern anatomy curriculum Turney (2007) argues, “anatomy must shake off the image of being old-fashioned and welcome clinical relevance” (p. 107). Those who support vertical integration hope that incorporating clinical content earlier in the curriculum will help students see the relevance of what they are learning and begin developing the critical thinking skills needed to apply their knowledge to medical practice (Dahle et al., 2002). 3DVT is ideally suited for increasing the integration of clinically relevant content because it can utilize real patient data and allow for easy demonstration of anatomical variations, anomalies, and pathologies (Trelease and Rosset, 2008).

The ability to create 3D images directly from patient imaging data allows teaching materials to connect normal anatomy to a wide range of case studies. Brown et al. (2012) created a stereoscopic 3D tutorial comparing normal abdominal anatomy to a ruptured aneurysm using an open source software that allows for volumetric rendering of CT scans. This tutorial was integrated into a first-year cardiovascular systems course and clinical material was emphasized by the inclusion of a patient vignette and information related to the risk factors, treatment, and complications of aneurysms. Brown et al. (2012) highlight how this kind of technology can aid integration of clinical content, stating:

> The ability to rapidly build a 3D model from a radiology investigation scan could be very useful in bridging the teaching of normal anatomy and pathology. This is particularly useful at present in systems-based curricula where normality, clinical skills and pathology are studied in an integrated manner. (p. 52)

Another example of using 3D models to bridge the teaching of normal anatomy and pathology is the 3D heart model created by Friedl et al. (2002) that allowed students to visualize different coronary artery stenoses and associated venous and/or arterial bypasses. This model included a presentation demonstrating stenosis of the coronary artery with subsequent myocardial ischemia, followed by visualizations showing the effect of an arterial graft on myocardial perfusion (Friedl et al., 2002). In this example students were able to go beyond learning fact-based information, to integrating their anatomical knowledge of the heart with the clinical importance of coronary artery stenosis, from disease presentation through treatment outcomes.

Finally, 3DVT can be used to teach clinically relevant anatomy at any level of the curriculum. Four coronary artery bypass techniques were demonstrated on the 3D heart model discussed above (Friedl et al., 2002). This material was then incorporated into an interactive multimedia textbook that included different levels of complexity for students, residents, and professionals. Similarly, Rengier et al. (2009) developed 3D radiology modules for use in the preclinical and clinical curricula. The preclinical modules gave students practice using imaging post-processing tools to create 3D models of normal anatomy and related example pathologies. Then, the clinical modules were designed to build on this foundational knowledge by emphasizing the ability to perform correct diagnoses based on radiological images. These examples show how 3D teaching materials can be used in the preclinical, clinical and postgraduate curriculum to help students successively build understanding of foundational anatomy and its application to clinical practice.

*Training in Postgraduate Education Programs*

Most descriptions of 3DVT use in postgraduate education are related to surgical specialties; for example, virtual reality surgical simulators or anatomical modeling of operative regions. Postgraduate training programs in surgical specialties require residents to expand their knowledge base while also acquiring unique and complex technical skills. Virtual reality surgical simulators provide a new teaching tool for surgical skills education, and allow trainees to practice technical skills in a safe, standardized environment (Arora et al., 2012). Additionally, 3D models allow residents to review complex anatomy that they may not be able to fully appreciate in operations limited by time (Balogh et al., 2004). 3DVT offers a wide variety of new methods to augment the training and assessment of surgical residents.

Virtual reality simulators can be used to help train residents in surgical procedures before they ever enter an operating room. Arora et al. (2012) describe the use of a simulator to give otolaryngology trainees practice with temporal bone dissections. The simulator used volumetric CT images of the temporal bone to create a stereoscopic display which allowed trainees to complete the dissection using a force-feedback hand stylus representing a virtual drill. The stylus allows the user to experience changes in pressure, and the computer records several performance measures such as excessive force and structure damage. Virtual reality simulators like these allow for unlimited practice with standardized models, can be tailored to the current skill level of the user, and offer objective skills assessment. Arora et al. (2012) emphasize the importance of feedback surgical simulators can provide, stating:

> Built-in, objective skills assessment provides meaningful performance measures that guide psychomotor and procedural skills development. Training surgical tasks and basic surgical skills through repetitive, proctored sessions improves both detection and analysis of surgical error. (p. 498)

A variety of teaching materials can be created using 3DVT that provide residents with means to review complex anatomy of surgical regions relevant to their specialty. For example the 3D heart model created by (Friedl et al., 2002) demonstrated surgical techniques, such as a closed coronary thromboendarterectomy and a complete distal anastomosis. This model demonstrated the relevant anatomy as well as the incision and suturing techniques for each procedure. Balogh et al. (2004) used intraoperative images obtained from a robotic camera to create a stereoscopic display that allowed residents review neurosurgical procedures. These interactive virtual reality displays allow users to control the surrounding environment to visualize anatomical structures from multiple views. The authors describe the 3D image display as an improved method for studying complex neuroanatomy because traditional intraoperative 2D images lack depth of field, interactivity, and wide viewing areas (Balogh et al., 2004).

**Assessment of 3D Technology**

Descriptions of 3DVTs that have been created for use in anatomy education provide insight into their potential as a teaching tool, and many academics have advocated for increased integration of their use in the medical curriculum. Skochelak (2010) reviewed 15 reports calling for medical education reform in North America and found that 13 of 15 reports had comments related to use of technology, including "recommendations to use developing technology to support new methods for learning" (p. 530). The importance and increased use of 3DVT in the medical curriculum suggests its educational effectiveness is worth scholarly assessment. Empirical studies assessing 3DVT use in anatomy education primarily report findings related to impact on student learning and satisfaction (Hackett and Proctor, 2016). While many studies indicate 3DVT has the potential to positively impact anatomy education, some mixed results suggest more specific data is needed on how they are being used in medical education before their effectiveness can be conclusively demonstrated.

Multiple studies assessing the effectiveness of 3DVT use in anatomy education have reported improved performance measures such as spatial and factual knowledge gains, decreased question response time, and improved structure localization and identification (Hackett and Proctor, 2016). Several randomized controlled studies found improved posttest performance of students using a variety of 3D technologies, including monoscopic displays (Nicholson et al., 2006; Müller-Stich et al., 2013), augmented reality textbooks (Ferrer-Torregrosa et al., 2015), and digital holograms (Hackett, 2013). Beneficial performance results of 3D technology use have been reported in a variety of anatomical content areas including head and neck vasculature (Cui et al., 2017), neuroanatomy (Ruisoto et al., 2012), surgical liver anatomy (Müller-Stich et al., 2013), and embryologic development (Marsh et al., 2008; Abid et al., 2010). In addition to improved performance measures, a large number of studies also report positive student perceptions of 3DVTs, including perceived ease of use, perceived educational value, and desire for continued future use (Hackett and Proctor, 2016).

While much of the published research shows promise in the use of 3DVT as a tool to enhance anatomy teaching and learning in medical education, the findings are not uniform and some studies have reported mixed or neutral findings regarding the effectiveness of 3DVT. A randomized controlled study that evaluated the use of 3D presentations to enhance student understanding of 2D medical imaging found no significant differences between the 2D and 3D trained group in their ability to correctly interpret 2D imaging (Metzler et al., 2012). Hu et al. (2010) found that a 3D model of the larynx was no more effective than written lecture notes at teaching laryngeal anatomy to undergraduate medical students. Similarly, a 3D model of the liver and biliary system neither enhanced nor hindered first- and fourth-year medical student learning of hepatobiliary anatomy (Keedy et al., 2011). However, Keedy et al. (2011) and Hu et al. (2010) both reported significantly higher satisfaction ratings in groups using the 3D models. Although the majority of studies report positive student perceptions of 3DVT effectiveness, a study of Obstetrics and Gynecology residents revealed that an interactive trainer utilizing a 3D pelvis model was not associated with significant improvement in knowledge or attitude scores related to pelvic anatomy and pelvic floor disorders (Hampton and Sung, 2010).

In an attempt to address the apparent mixed results of studies assessing 3DVT, Yammine and Violato (2015) conducted a meta-analysis to examine the effectiveness of 3DVT in anatomy education compared to traditional teaching approaches such as lecture, textbooks, and 2D digital images. Their analyses of the weighted mean difference effect sizes of 27 studies, that included 2,128 participants, found significant advantage of 3DVT over 2D methods for both spatial and factual knowledge acquisition. In addition, their analysis of 4 studies with a pretest/posttest design found knowledge acquisition after 3DVT interventions was significantly improved. Finally, their meta-analysis of participant perceptions of 3DVT use showed significantly higher user satisfaction, perceived effectiveness, and desire for future use of the technology, but no significant difference in the perceived ease of use or image realism.

While the results of the meta-analysis conducted by Yammine and Violato (2015) are promising for the effectiveness of 3DVT as a teaching tool, there are notable limitations to the study. First, as the authors point out they found few studies comparing 3DVT to dissection and prosection, limiting comparison of 3DVT to fundamental teaching methods in medical anatomy education. Additionally, there are two studies with large effect and sample sizes skewing the results, and these studies contain limitations which make their inclusion problematic. For example, the study containing the largest sample size compared embryogenesis taught either using lectures with chalk drawings or using an interactive multimedia DVD ROM with 3D simulations (Abid et al., 2010). Not only is teaching with chalk drawings rare in most modern medical schools, but the type of self-directed learning provided by the 3D multimedia may not be equivalent to the didactic nature of the chalk drawing lessons. Additionally, because chalk drawings lack shading that help students visualize movement, depth, and spatial relationships they are unlikely to be effective for teaching a dynamic process like embryonic development.

The second study of the meta-analysis which had a large effect and sample size was conducted by Beermann et al. (2010), who assessed student ability to correctly identify structures of the liver on 2D, 3D, and 3D colored models. The results of this study only suggest that students were better able to initially identify structures on 3D models. Therefore, this study should not have been included in the meta-analysis examining improvements in measures of spatial knowledge. Overall, the meta-analysis conducted by Yammine and Violato (2015) compared 3DVT to a limited number of other teaching methods and the results may have been skewed by large, potentially problematic studies. These limitations of the meta-analysis, taken together with the mixed results of published studies suggest ambiguity still exists regarding the effectiveness of 3DVT as an anatomy teaching tool and what its role should be in medical education.

Possible explanations for the mixed results of 3DVT assessment include variations in study design, type of technology used, and factors related to the curriculum. Explanations related to variations in study design point to differences in sample sizes, interactivity of the 3D visualization, and length of the intervention (Nicholson et al., 2006). In their review examining the quality of research published on 3D models Azer and Azer (2016) note the absence of a validated knowledge assessment tool in many studies. Some additional explanations highlight specific curricular elements such as student background, learning environment, subject matter, and instructional method (Hoyek et al., 2014; Peterson and Mlynarczyk, 2016). Because 3DVT is likely to be used in the medical curriculum in a multitude of different ways, understanding how these variations in curricular factors affect student learning is worth further investigation.

Several studies reported findings that highlight how specific curricular elements may influence student learning when using 3DVT. For example, although Hampton and Sung (2010) reported no overall significant difference between scores of residents randomized to 3D versus traditional teaching, when stratified by year of training they found that the post-intervention knowledge scores of first-year residents using the 3D pelvis trainer were significantly higher. Another study assessing the effectiveness of a web-based learning module on embryology found that students using the modules containing 3D animations only performed better than those given traditional resources when they used the 3D resource after having already been exposed to the content (Marsh et al., 2008). Yammine and Violato (2015) conducted subgroup analyses as part of their meta-analysis and reported that 3DVTs produced significantly higher spatial knowledge gains compared to 2D methods for trunk and abdominal anatomy but yielded no significant results for content covering anatomy of the brain, liver, or larynx. These studies suggest that factors of the curriculum such as the level of study, arrangement of content and experiences, and subject matter may all play a role in the effect of 3DVT use on student learning.

Discussions surrounding the effectiveness of 3DVT in anatomy education should include careful consideration of how curricular design may impact results. Azer and Azer (2016) note that:

> There is a need for in-depth research in this new area that can provide answers to questions about the purpose of using 3D anatomy models in the curriculum, and the place of 3D anatomy teaching in the undergraduate curriculum and how we can assess the impact of using 3D models on student's learning. (p. 96)

A deeper understanding about the specific ways in which 3DVT is being implemented in the medical curriculum can help frame future research into the effectiveness of 3D technology and provide new knowledge to support productive discussions about curricular reform and design.

**Summary**

Anatomy education forms an integral part of the preclinical, clinical, and postgraduate medical curricula, with teaching methods that vary from didactic lectures and cadaveric dissection to problem-based learning and near-pear teaching activities. 3DVT offers promising new teaching tools that are being used at all levels of the medical curriculum. These computer-based 3D visualizations utilize interactive controls, real patient scans, and virtual environments to create teaching tools that improve the ability view complex spatial relationships, increase the integration of clinical content, and provide innovative training methods for postgraduate education programs (Friedl et al., 2002; Trelease and Rosset, 2008; Arora et al., 2012; Brown et al., 2012). While 3DVT shows promise as a tool for anatomy education, careful assessment is needed regarding its effectiveness to accurately evaluate its true benefit to medical education.

Research examining the impact of 3DVT on student learning and satisfaction shows promise in its effectiveness as a teaching tool, but some mixed results suggest further research is needed. Evidence suggests that curricular factors such as the level of study, arrangement of content and experiences, and subject matter may all play a role in the effect of 3DVT use on student learning (Marsh et al., 2008; Hampton and Sung, 2010; Yammine and Violato, 2015). The mixed results of 3DVT assessment may reflect the fact that current analysis is not being placed into a curricular framework or informed by an understanding of how 3D technology is being used within the medical curriculum. However, no such framework exists, and past research has not identified key variables related to 3D technology use.

With the increased demands on anatomy education to utilize innovative teaching tools to improve student understanding of clinically relevant anatomy at all levels of the curriculum, it is imperative to understand the role that 3DVT plays in the medical curriculum. Productive discussion concerning the assessment and integration of 3DVT in medical education requires a deeper understanding of the current use of 3DVT than currently exists. To address the gap in the literature this study qualitatively explored faculty use of 3DVT for anatomy education in the medical curriculum. In addition, this study examined the similarities and differences of 3DVT use for anatomy education in the preclinical, clinical, and postgraduate curricula.

# CHAPTER 3: METHODOLOGY

Literature detailing 3DVT use in the medical curriculum is limited to explanations of use in studies assessing their effectiveness and articles describing the development of specific technologies. To date, there exists no comprehensive study detailing how faculty use 3DVT for anatomy education, or how 3DVT is used in specific aspects of the medical curriculum. The purpose of this study was to investigate how faculty use 3DVT for anatomy education, so that the knowledge gained can be used to inform more productive discussions about the assessment and integration of 3DVT use in the medical curriculum. Specifically, this study was designed to gain an in-depth understanding of how faculty use 3DVT for anatomy education in preclinical courses, clinical clerkships, and postgraduate residencies, and to describe the similarities and differences in faculty use of 3DVT across the phases of the medical curriculum.

This study utilized a qualitative methodology, so that the themes generated from one-on-one interviews with faculty participants could be used to develop a framework of 3DVT use in the medical curriculum. Because little was known about the use of 3DVT in the medical curriculum, the use of qualitative methods was selected due to its ability to develop a deep, detailed understanding of complex phenomena (Merriam and Tisdell, 2015). The experiences of faculty participants in this study provide an essential perspective because faculty make important decisions regarding the use of 3DVT in the curriculum, and ultimately, the success of technology use in education is highly dependent on the perceptions of the teachers who use it (Mumtaz, 2000). An additional product of this dissertation was the development of a questionnaire based on the themes generated from the qualitative exploration of 3DVT use. This questionnaire provides an instrument for use in future research to quantitatively examine the prevalence of the themes generated in this study.

In order to examine how faculty use 3DVT in the medical curriculum a definitional framework of a curriculum was needed to guide the inquiry. Lattuca and Stark's (2011) academic plan model was used to focus the research questions of this study to ensure they covered specific elements of the curriculum which may be important for consideration. Specific sub-questions framed by this model explore the use of 3DVT as an instructional resource, and its use as a resource as it relates to the other elements of the curriculum. The components of the academic plan selected for examination in this study included instructional resources, purposes, content, sequence, instructional processes, and evaluation. With these elements of the academic plan model providing a guiding framework, the research questions addressed in this study include:

1) In what ways do faculty use 3DVT for anatomy education within the preclinical, clinical, and postgraduate medical curriculum?

    Sub-questions (a-f) are framed according to Lattuca and Stark's (2011) academic plan model:

    a. How do faculty use 3DVT as an instructional resource?
    b. What do faculty see as the purpose of anatomy education at their respective level and how do they use 3DVT to try to achieve these goals?

c. What content is taught using 3DVT, and what knowledge, skills, and attitudes are faculty trying to convey?

d. How do faculty arrange the subject matter and learning experiences associated with 3DVT use? How is sequence used to try to achieve desired learning outcomes?

e. Into what type of instructional processes are 3DVTs incorporated?

f. How are 3DVTs used to evaluate student learning?

2) What similarities and differences exist in how faculty use 3DVT for anatomy education in the preclinical, clinical, and postgraduate medical curriculum?

**Overview of the Research Design**

The aim of this study was to investigate faculty perspectives of 3DVT use for anatomy education within the medical curriculum and compare 3DVT use across the preclinical, clinical, and postgraduate phases. This study utilized a two-phase design, which consisted of a qualitative phase followed by a questionnaire development phase. The first phase of this study included the collection and analysis of qualitative data from one-on-one, semi-structured interviews with faculty who use 3DVT for anatomy education in preclinical courses, clinical clerkships, or postgraduate residency programs. During this phase data was simultaneously collected and analyzed using the constant comparative method (Glaser, 1965). Phase one was followed by phase two, where a survey instrument was built based on the initial qualitative findings. This two-phase approach allowed for the design of quantitative instrument that is grounded in the perspectives of faculty participants. A diagram outlining the timeline and procedures for the study demonstrates this phasic approach (Figure 3.1).

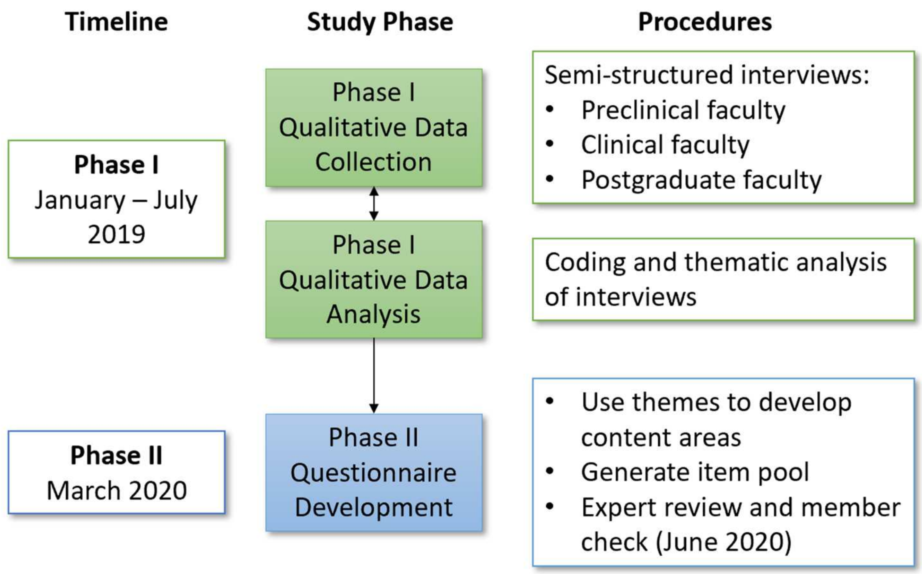



Figure 3.1: Timeline and Study Design Overview

**Phase I: Collection and Analysis of Qualitative Data**

This section details the methods of qualitative data collection and analysis used in phase one of this study. It includes a discussion of study participants, participant selection, data collection, and data analysis. Qualitative methods were used in the first phase of this study to explore participant perspectives of 3DVT use, allowing for an in-depth understanding, and comparison, of faculty use of 3DVT within specific aspects of the medical curriculum.

*Participants*

The participants in this study were basic science faculty, clinical faculty, and fellows from North American medical schools and teaching hospitals, who had teaching responsibilities in at least one of the following areas: 1) preclinical anatomy courses, 2) clerkship rotations, or 3) residency programs. According to the Association of American Medical Colleges (AAMC, 2018) and the American Association of Colleges of Osteopathic Medicine (AACOM, 2018) at the time of this study there were 151 accredited allopathic medical schools, 34 accredited colleges of osteopathic medicine, and nearly 400 teaching hospitals in the United States. Additionally, according to the Association of Faculties of Medicine of Canada (AFMC, 2018) there were 17 accredited allopathic medical schools in Canada in the 2018-2019 academic year.

To be included in the study participants needed to have experience using a 3DVT in their teaching role. For the purpose of this study 3DVT included any monoscopic, stereoscopic, virtual reality or augmented reality technologies as defined by Hackett and Proctor (2016). Participants were described as preclinical, clinical, or postgraduate faculty based on their primary area of teaching that included the use of 3DVT. Preclinical faculty participants included course directors and instructors who had responsibility for delivering anatomy content (gross anatomy, histology, embryology, or neuroanatomy) to first- and second-year medical students. Clinical faculty participants included instructors, clinical educators, or clerkship directors, who had direct responsibility for third- and fourth-year student education during a given clerkship rotation. Postgraduate faculty participants included instructors, residency program directors, or fellows who were responsible for at least some component of resident education in a given specialty.

The decision to include participants from a wide range of schools and specialties was made because increased variation can promote rich, in-depth understanding of the phenomenon being studied (Merriam and Tisdell, 2015). Including schools across North America, and a variety of specialties created a large variation of participants who use different types of 3DVTs in a wide range of courses, subspecialties, and teaching activities. In his discussion of utilizing variation in sampling Patton (2015) highlights the strength of this strategy stating, “Any common patterns that emerge from great variation are of particular interest and value in capturing the core experiences and central, shared dimensions of a setting or phenomenon” (p. 283). The large variation of participants in this study will allow for greater insight to be gained about how 3DVT is being used in multiple types of medical curricula.

In order to allow for the rich participant descriptions needed for thematic analysis a goal was set to include seven participants from each level of the curriculum (preclinical, clinical, and postgraduate). Because clinical faculty participants who used 3DVT for teaching in clerkships were unable to be recruited, it was decided to include one clerkship director who was interested in future use of 3DVT, and one clerkship director who used 3D ultrasound in their own clinical practice. These clinical faculty participants were included to provide insight into the curriculum of clinical clerkship rotations, and potential of 3DVT use in these areas. The final number of preclinical (n=7) and postgraduate (n=6) participants was determined by saturation. Thus, a total of fifteen (n =15) participants were recruited for interviews in the first phase (7 preclinical, 2 clinical, and 6 postgraduate).

*Participant Selection*

Approval from the Institutional Review Board (IRB) at Indiana University was sought before beginning participant recruitment, and the study was granted exempt status in December 2018 (IRB protocol #1808221275). The first round of recruitment consisted of calls for participants that were sent out in January 2019 through the electronic mailing lists and online forums of the following professional organizations: 1) American Association for Anatomy (AAA), 2) AAMC's Group on Educational Affairs (GEA), and 3) American Association of Clinical Anatomists (AACA). The recruitment letter included a brief description of the study and a link to a questionnaire asking respondents to fill out information on their use of 3DVT for teaching so that their eligibility to participate could be determined. Additionally, a study information sheet was included with each recruitment letter, either as a separate attachment or a link that allowed for its download. Participants were offered a $50 Visa gift card to compensate them for the time needed to complete interviews. The materials used for recruitment are included in Appendix A.

In an effort to recruit additional clinical and postgraduate participants a second phase of recruitment was used. In this second phase calls for participation were sent through three outlets: 1) Twitter, 2) DR-ED listserv, and 3) personal contacts. In February 2019 a flyer with the study description and researcher contact information was shared with the #MedED twitter handle and retweeted by colleagues at Indiana University. Additionally, the recruitment email was sent out on the DR-ED listserv. Finally, the primary author/researcher reached out to colleagues in her professional network asking for help identifying people who may be interested in participating. Colleagues from several institutions forwarded the recruitment email to contacts in their network, and others provided contact information of clerkship and residency program directors that the researcher emailed recruitment letters to directly.

A total of 12 preclinical faculty members completed the participant screening questionnaire in response to the recruitment letters sent out through the AAA, GEA, and AACA mailing lists. Emails requesting participation in the study were sent to 10 of these respondents who were determined to be eligible to participate, and interviews were scheduled with 7 who agreed to participate. Recruitment emails sent out through personal contacts led to responses from 7 postgraduate participants who were eligible to participate, and interviews were scheduled and completed with 6 of these respondents. Finally, two clinical faculty participants responded to emails sent through personal contacts, and though they were not originally eligible to participate, they were included in order to provide important perspectives on the clerkship curriculum. Once respondents agreed to participate, they were assigned a unique ID to keep their identity confidential (preclinical P1-P7; clinical C1-C2; and postgraduate R1-R6), and instructions on joining the interview session were sent via email.

*Data Collection*

Semi-structured, one-on-one interviews were conducted with selected participants to explore their experiences of using 3DVT in the medical curriculum. The main purpose of these interviews was to gain insight into how faculty approach the use of 3DVT in the medical curriculum. The use of interview data was selected for this study because the decisions that faculty make about how to use 3DVT in the curriculum cannot be observed. As Patton (2015) explains:

> We interview people to find out from them those things we cannot directly observe . . . We cannot observe feelings, thoughts, and intentions. We cannot observe behaviors that took place at some previous point in time. We cannot observe situations that preclude the presence of an observer. We cannot observe how people have organized the world and the meanings they attach to what goes on in the world. We have to ask people questions about those things. The purpose of interviewing, then, is to allow us to enter into the other person's perspective. (p. 426)

Thus, interviews allowed for insight into the perspectives of faculty about the decisions they make, the intentions they have for the use of 3DVT, and their feelings surrounding its use.

The interviews were semi-structured, lasted approximately 20-40 minutes, and were guided by an interview protocol (Appendix B). The interview guide included a mix of more and less structured questions and provided the researcher flexibility in the wording and order of questions. This guide included primary questions along with options for follow-up questions and probes to be used when more information was needed, allowing for deeper exploration into topics of interest. The use of a guide provided consistency by ensuring that the main topics needed to answer the research questions were addressed in each interview. At the same time, the use of a less structured guide, with open ended questions, allowed the researcher to better explore the individual perspectives of participants who make meaning of their experiences in unique ways.

One-on-one interviews were conducted from February to April 2019, and because participants were geographically dispersed each was given a choice to complete the interview online, in-person, or via telephone. After obtaining permission from participants all interviews were audio recorded and the files were uploaded to a secure Box folder at the completion of each interview. Ten participants elected for online interviews, which were conducted and recorded using the web conferencing platform Zoom (Zoom Video Communications 2019, Version 4.3.4). Three participants requested telephone interviews which were recorded using the cellular phone app Call Recorder – ACR (NLL Apps 2019, Version 32.7). Finally, two in-person interviews were recorded using the cellular phone app Otter Voice Meeting Notes (Otter.ai 2019, Version 2.0.13).

To begin, the researcher introduced herself, described the study, and gave participants an opportunity to ask questions related to the interview, researcher, and/or purpose of the study. Once permission was obtained to record the session the researcher asked participants open-ended questions about their teaching responsibilities and program or class setting. The next set of questions asked participants to talk about the 3DVT they use and how it is used for anatomy education. The final portion of the interview contained questions related to sub-questions (a-e) of the first research question. These questions asked participants to talk about how they consider(ed) different aspects of the curriculum (e.g., academic plan elements such as sequence, content, etc.) when implementing 3DVT. At the end of the interview participants were informed about the member checking process and told upon completion they would be receiving a copy of the results and questionnaire. Specifics of the member check are discussed in further detail in a later section of this chapter.

*Data Analysis*

A thematic analysis of the interview data was used to generate a framework of how faculty use 3DVT in the medical curriculum. Collection and analysis of qualitative data occurred simultaneously using the constant comparative method (Glaser, 1965). In this method the researcher analyzes data as it is collected, comparing newly collected data to the existing categorizations and developing themes. The researcher continually compares findings and makes necessary adjustments to codes and categories so that they capture recurring patterns that are representative of all the data being collected. Concurrently, the researcher reflects on the data to inform additional future questions so that emerging concepts can be discussed with participants (Merriam and Tisdell, 2015). This process begins as highly inductive data analysis through the construction of categories and moves toward a more deductive analysis as tentative category schemes are tested against the data (Merriam and Tisdell, 2015). The constant comparative analysis continues until theoretical saturation is reached, and the researcher has categories representing major themes.

After each interview the audio recording was transcribed by the researcher and the transcript uploaded to Dedoose (SocioCultural Research Consultants 2019, version 8.2.12) for data analysis. Once uploaded, the researcher read through the transcript noting initial reactions, general impressions, and/or tentative themes. During this initial data analysis open coding was used to identify significant segments of the transcript which were responsive to the research questions. Coding is used during analysis to create conceptual categories, and is defined by Creswell and Clark (2017) as, “the process of grouping evidence and labeling ideas so that they reflect increasingly broader perspectives” (p. 214). Dedoose allows codes to be applied to highlighted sections of the transcript, and users can pull up all sections of text in the data linked to any given code.

After open coding, the researcher began analytical coding by grouping similar codes together to construct categories (Merriam and Tisdell, 2015). During this process some categories may be subdivided, combined, or placed under broader themes. Richards (2014) explains that analytical coding “comes from interpretation and reflection of meaning” (p. 135), so that themes inductively emerge from the data. The emerging themes were organized into overarching groups based on the academic plan elements they addressed: instructional resources, purposes, content, sequence, instructional processes, or evaluation. During this process the researcher kept a notebook for documenting the developing categories and tentative themes. Another notebook was used as a journal for the researcher to record personal notes about impressions, thought processes, and potential biases.

As data collection continued new transcripts were uploaded to Dedoose and preliminary coding of these transcripts was conducted with the existing scheme of codes and categories in mind. In following the constant comparative method new data was continually compared to previously coded data to look for recurring regularities. During this process new codes were added, categories were renamed and reorganized and the criteria for allocating data to each category became more clearly defined. After the last interview was transcribed and coded, and it was determined saturation had been reached, a final round of analysis was conducted. During this final analysis codes for each theme were reviewed for consistency across the dataset and categories underwent a final round of revision. This is primarily a deductive process as the existing organization of categories is tested against the data (Merriam and Tisdell, 2015).

*Credibility and Trustworthiness*

In any research it is important to produce reliable and valid data so that results can be trusted and used in meaningful ways. In qualitative research the terms trustworthiness and credibility are commonly used when discussing the validity and reliability of a study (Merriam and Tisdell, 2015). This section describes strategies which were used to enhance the credibility and trustworthiness of the results.

**Member Checks**

Member checks are an important, commonly used method for addressing the credibility of qualitative research (Merriam and Tisdell, 2015). By seeking feedback from participants member checks help identify areas where the researcher may have misinterpreted the meaning of what was said. The results section was shared with interview participants to solicit feedback about how well the researcher's interpretations reflect their own realities. In addition, the interview participants were asked to participate in the expert review of the questionnaire which was developed from the qualitative findings. In this way participants had the opportunity to provide feedback on the clarity of the questionnaire content and to what level they felt the included items encompassed important aspects of their own 3DVT use.

### Clarifying Researcher Bias

In qualitative studies the researcher is the instrument for data collection, and clarifying potential biases, dispositions, and assumptions of the researcher is an important part of ensuring study credibility and trustworthiness (Merriam and Tisdell, 2015). The researcher notes that she has experience teaching in anatomy, histology, and neurology preclinical courses, but has had no involvement teaching in clinical or postgraduate curricula. Additionally, the researcher has experience using 3DVT and has created 3D content for use in a first-year medical gross anatomy course. This experience may have created assumptions on how 3DVT is used in the preclinical curriculum. In order to keep track of potential biases the researcher took careful notes in a journal about how categories were determined and what decisions were made during analysis. Potential biases were also discussed with the research team to understand how the researchers experience might influence data analysis and interpretation.

### Rich Descriptions

The use of rich, thick descriptions help readers determine what other settings or contexts the results might apply to. Merriam and Tisdell (2015) explain rich description as, “providing enough description to contextualize the study such that readers will be able to determine the extent to which their situations match the research context, and, hence, whether findings can be transferred” (p.259). To increase the transferability of the results of this study, the researcher has presented a detailed description of the setting and included participant quotes in the write up of study findings.

**Phase II: Questionnaire Development**

Building on the exploratory results from phase one, phase two consisted of the development of a quantitative questionnaire. Using the themes generated from the qualitative phase of this study to develop survey items allows for the creation of a quantitative instrument which is grounded in the perspectives of faculty participants (Creswell and Clark, 2017). The creation of this questionnaire provides a tool for future research to further examine the prevalence of themes found in the qualitative data. Currently no instrument exists that provides a measure of faculty use of 3DVT, so the purpose of developing this questionnaire was to provide a tool for measuring faculty use of 3DVT that could be applied across different settings of medical education.

After the qualitative data collection and analysis for phase one was complete the resulting themes and significant statements were used to define the measures and create item pools for the questionnaire. The overarching categories representing the academic plan elements were used to define the questionnaire constructs. Next the researcher developed a set of items for examining the characteristics of each construct by using the subthemes and participant quotes to inform question creation. The specific ways in which the qualitative results informed the development of questions is discussed in more detail in the following chapter. Finally, an expert review was conducted to assess the fit and relevance of items, as well as the overall clarity of the questionnaire.

# CHAPTER 4: RESULTS

The purpose of this study was to investigate how faculty use 3DVT for anatomy education in the preclinical, clinical, and postgraduate medical curriculum. A further aim of this study was to describe the similarities and differences in faculty use of 3DVT across these phases of the medical curriculum. This study utilized an initial qualitative phase consisting of interviews with 15 faculty members who had teaching responsibilities in preclinical courses, clinical clerkships, and residency programs. In a second phase the findings of these interviews informed the development of a new quantitative survey instrument. The purpose of this chapter is to present the qualitative findings, as well the details on development of the questionnaire. This study was guided by two primary research questions:

1) In what ways do faculty use 3DVT for anatomy education within the preclinical, clinical, and postgraduate medical curriculum?
2) What similarities and differences exist in how faculty use 3DVT for anatomy education in the preclinical, clinical, and postgraduate medical curriculum?

The findings of the thematic analysis conducted in this study are organized around answering these questions. The first section of this chapter provides information on the participants of the qualitative phase. The second section presents the themes that emerged related to faculty use of 3DVT within the medical curriculum. This section is organized according to the specific sub-questions related to the academic plan framework and discusses 3DVT use related to each element of the academic plan. Specific sub-questions are restated at the start of the segment in which they are addressed. The third section describes the similarities and differences in how preclinical, clinical, and postgraduate faculty use 3DVT. After the presentation of qualitative results, a final section of this chapter details how questionnaire items were developed based on the qualitative results.

**Participant Information**

Seven participants who use 3DVT for preclinical education agreed to participate, and all of these participants used 3DVT for teaching in first- and second-year gross anatomy courses. Four of these participants taught at US allopathic medical schools, two at Canadian allopathic medical schools, and one at a US college of osteopathic medicine. Although the researcher was unable to recruit any participants who used 3DVT for teaching in clinical clerkships, two clerkship directors were included as participants to gain insight into the clinical curriculum. One clinical participant was a surgical clerkship director who was interested in future use of 3DVT, and the other was a clerkship director who frequently had students in the cardiology clerkship observe the use of 3D ultrasound in clinical practice.

Finally, seven potential participants who use 3DVT for teaching in a variety of residency programs agreed to participate, but one participant was unable to complete the interview due to time constraints. Four of the postgraduate participants were residency program directors, each from a different specialty including neurosurgery, OB-GYN, nuclear medicine, and ophthalmology. Another postgraduate participant was an anatomy course instructor who led anatomy review sessions for several different residency programs, and one was a fellow who had a direct role in training surgical residents. Participant demographics are included in Table 4.1 and individual interview lengths can be found in Table 4.2.

Table 4.1: Participant Demographics

| | | MALE | FEMALE | TOTAL |
|---|---|---|---|---|
| **Gender** | | 12 (80%) | 3 (20%) | 15 (100%) |
| **Level** | Preclinical | 6 (40%) | 1 (7%) | 7 (47%) |
| | Clinical | 1 (7%) | 1 (7%) | 2 (13%) |
| | Postgraduate | 5 (33%) | 1 (7%) | 6 (40%) |
| **Degree** | MD | 7 (47%) | 2 (13%) | 9 (60%) |
| | PhD | 4 (27%) | 1 (7%) | 5 (33%) |
| | Other | 1 (7%) | 0 (0%) | 1 (7%) |
| **Region** | Western | 4 (27%) | 0 (0%) | 4 (27%) |
| | Midwestern | 5 (33%) | 2 (13%) | 7 (47%) |
| | Southern | 0 (0%) | 0 (0%) | 0 (0%) |
| | Northeastern | 1 (7%) | 1 (7%) | 2 (13%) |
| | Canada | 2 (13%) | 0 (0%) | 2 (13%) |

Table 4.2: Individual Interview Lengths in Minutes

| **Preclinical** | | **Clinical** | | **Postgraduate** | |
|---|---|---|---|---|---|
| ID | Length | ID | Length | ID | Length |
| P1 | 54:59 | C1 | 17:15 | R1 | 9:48 |
| P2 | 38:37 | C2 | 20:28 | R2 | 25:01 |
| P3 | 26:10 | | | R3 | 29:09 |
| P4 | 23:26 | | | R4 | 30:10 |
| P5 | 44:18 | | | R5 | 26:04 |
| P6 | 53:46 | | | R6 | 25:17 |
| P7 | 27:16 | | | | |

For the member check all participants were sent a completed copy of the results chapter and questionnaire and were asked to provide feedback on the accuracy of the researchers' interpretations of the data and clarity of the questionnaire items. The researcher was unable to contact two of the participants whose emails were no longer in service. Of the remaining thirteen participants, only one provided feedback on the results. This participant indicated they felt the results were likely an accurate reflection of those included in the study, but also expressed a belief that respondents were likely to be early adopters who are more inclined to have positive attitudes towards 3DVT. Finally, five participants responded with feedback related to the questionnaire, and this feedback is discussed with the presentation of the items in the final section of this chapter. While the response rate was low, it was determined to be reasonable given that at the time the member checks were sent out participants were likely facing an increased demand on their work schedules due to the impact of the COVID-19 pandemic on education and health care fields.

**Themes of Faculty 3DVT Use**

A thematic analysis was used in order to answer the first research question related to faculty use of 3DVT in the medical curriculum. This process was guided by Lattuca and Stark's (2011) academic plan model, which provided a definitional framework of the curriculum. The use of this framework allowed individual components of the curriculum to be considered by examining faculty use of 3DVT in relation to each of the selected academic plan elements. During the thematic analysis emerging themes were organized into categories based on which academic plan element they addressed:

1) Instructional Resources, 2) Purposes, 3) Content, 4) Sequence, 5) Instructional Processes, or 6) Evaluation.

Figure 4.1 presents a schematic of the academic plan elements explored in relation to faculty use of 3DVT in the medical curriculum. In the following sections the themes and subthemes related to each academic plan element will be explained in detail. When taken together the themes generated for each element provide an overall framework for understanding how faculty use 3DVT within the medical curriculum.

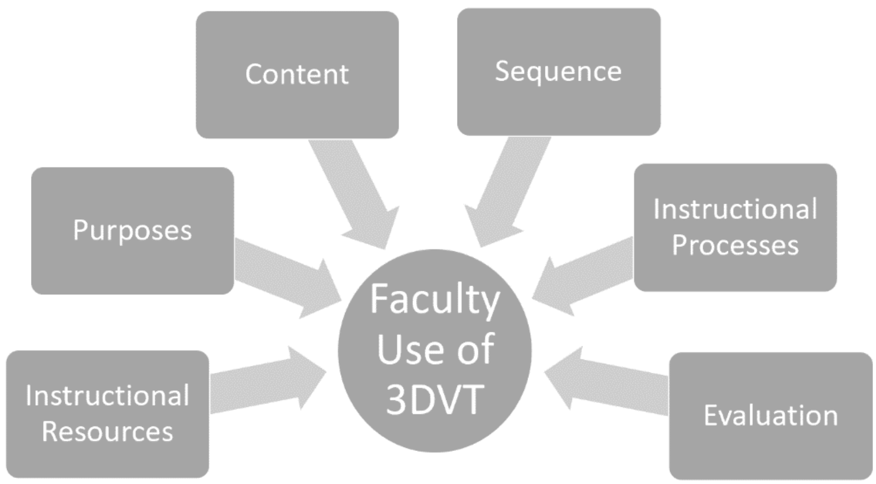



Figure 4.1: Academic Plan Elements Explored in Relation to Faculty Use of 3DVT

*Instructional Resources*

Lattuca and Stark (2011) define instructional resources as “the materials and settings to be used in the learning process” (p. 5). Instructional resources represent an important component of the curriculum because they shape student learning and can include materials such as textbooks, presentation slides, and visual aids. 3DVT can be examined as an instructional resource used in the medical curriculum. In exploring this academic plan element, themes generated from analysis were used to answer the following research sub-question:

- How do faculty use 3DVT as an instructional resource?

Four major themes in this category describe how faculty participants used 3DVT as a resource with the intention of 1) Filling a Deficiency, 2) Improving Visualization, 3) Customizing Learning Experiences, and 4) Enhancing Learning Experiences. Subthemes explore the specific ways participants utilized various aspects of the technology in order to work towards each of these goals. The following sections discuss each of the four themes and related subthemes, before a final section summarizes the themes related to 3DVT use as an instructional resource.

**Filling a Deficiency**

Many faculty participants described how they used 3DVT as a resource to fill in for what they viewed as a deficiency of other resources. Specifically, participants talked about how they use 3DVT with the intent to a) reduce dependence on wet labs, b) provide alternative visualization, c) increase accessibility, d) improve time efficiency, and e) create low risk training. Some participants talked about how they replaced a particular resource with 3DVT, while other participants described how they used 3DVT to augment other resources to supplement teaching in certain areas of need.

*Reduce Dependence on Wet Labs*

Several participants discussed using 3DVT to reduce dependence on wet labs such as cadaveric dissection labs or animal-based skill labs. The expense, time constraints, and negative perceptions associated with labs were all cited by participants as reasons for why they use 3DVT to supplement or replace wet labs. One participant reflected on the reasons why 3DVT was used to replace traditional dissection labs in their preclinical curriculum:

> The decision was made before I even got here that we were going to do no wet lab anatomy, it's all virtual. And that came out of two reasons. One is building a wet lab would cost us about $10 million dollars we figure, and about $2 million upkeep. So, we decided that what we would do is go virtual. The other part of it was that both the Dean and the Vice Dean had very poor memories of anatomy . . . Our Founding Dean was a pathologist and she felt it had no bearing on her ability to be a pathologist.

While this participant discussed how 3DVT was used to replace cadaver labs, others talked about using 3DVT to augment teaching in wet labs. One such participant discussed the advantages of using 3D neuroanatomy models for training neurosurgical residents, "I think it's time, effort, it's, you know, cadaveric labs are expensive, time consuming. And if there's other ways to supplement them, to decrease our dependence on the cadaver lab this is ideal." Rather than using 3DVT to replace teaching in wet labs, these participants expressed feelings that 3DVT was well suited for augmenting teaching in cadaver or animal labs.

*Provide Alternative Visualizations*

A majority of participants talked about how difficulty seeing areas of complex anatomy when using more traditional teaching modalities led them to explore the use of 3DVT to provide alternative visualizations. Participants mentioned a variety of structures or areas which were difficult to adequately visualize using methods such as models, fixed cadavers, or medical imaging. One participant described how they used 3DVT for viewing complex reproductive structures of the pelvis:

> I think the relationships of where the ovaries are, and how the broad ligament goes over the fallopian tubes, it's tough [to understand] right? It's tough, because it's so different in the fixed cadaver than it is a live person. And so, while I had shown videos of the laparoscopic approach, and they can see that in a healthy 21-year-old volunteer, that only goes so far. And so, you know, being able to move it around, I know that there was a lot of positive feedback when it came to something along those lines.

Many participants cited similar issues with the unrealistic nature of fixed tissue, as well as difficulties adequately dissecting out small or complex structures such as branches of the genitofemoral nerve or the inner ear.

While some participants discussed the limitations of viewing structures in cadavers, others described limitations of using models. One participant discussed the potential of using virtual reality to provide alternative visualizations to models:

> If I can think of something you can't see in a model somehow, then maybe somehow VR would be better or something that I couldn't visualize any other way, then that would be a great use of VR because then we'd be finding something that we know you can't see any other way. So, VR would be better because it's better than nothing. Right?

Similarly, another preclinical participant also talked about using virtual dissection to address what he saw as a deficiency in teaching with models:

> So even though a model gives you a 3D projection, you know, you can sometimes take a plastic piece of muscle off here, and a plastic piece of something off there. But it's not quite the same way of being able to go through layer by layer by layer, and work through, that the 3D technologies allow.

This participant utilized 3DVT as a resource because they felt it was better able to demonstrate the three-dimensionality of layered structures than would be possible using plastic models. Finally, several participants mentioned the lack of detail in medical imaging as a reason to use 3DVT which provided the ability to zoom in to view greater detail, or even add details to virtual models through custom programming.

*Increase Accessibility*

The convenience of 3DVT was frequently discussed by participants, who used 3DVT technology as an instructional resource to increase accessibility for students when other methods were not readily available at home or in the clinics. One participant noted, “You can readily navigate them in 3D space on your computer, which is very nice, rather than carrying a skull with you at all times or carrying a brain or other structures.” Like this participant, several others talked about the ability to access 3D models on multiple devices, which were more portable than models or laptops, and thus allowed the resource to be used anywhere including at home or in clinics. Another participant noted that accessibility was not only important in terms of where students could access the 3D resource, but also when it was accessible:

> For our group, because we're sort of a blended distance educational learning setting, I wanted our students to be able to learn at any time at any place. So, for me, access was important, because I'm hoping we can begin to think about education as something that becomes more learner-focused. And some folks maybe learn a little bit better from 6pm to 8pm, as opposed to 8am to noon. And so, it provides a little more flexibility in that realm, so that learners can sort of tailor things at their own pace and at their own time, that's really my big reason for wanting access to be high.

This participant, and others, noted that by having 3D resources available at any time they hope to better address the needs of different types of learners who may prefer studying at different places, times, or paces.

A small subset of participants discussed how they use 3DVT to increase accessibility to learning in situations where time for students in the operating room or with patients is limited. In these cases, there is a shortage of available patients or chances to sit in on operations, and faculty use 3DVT to provide all students equal access to resources that can standardize the learning experience. One residency program director described how they used a virtual lab to increase student and resident exposure to clinical eye examinations, explaining, "they get anatomic and clinical correlation, and they get to see abnormal exams. And no patient was inconvenienced in this, it is all done virtually." By using virtual models to recreate ophthalmology exams this faculty member aimed to increase accessibility by giving each student an opportunity to practice an examination, and see a variety of abnormal exams, that they otherwise would not have had the opportunity to view in a typical clinical setting.

*Improve Time Efficiency*

With a limited amount of time in the curriculum, many participants talked about using 3DVT because it allowed them to improve time efficiency and the ability to cover required content. One residency program director discussed the benefits of students using 3DVT for learning relationships:

> I think it saves time. Having the 3D visualization saves time, in terms of that initial hurdle of getting to learn the three-dimensional orientation of everything. I do remember struggling many hours, through my atlases and moving from image to image and back and forth and book to book and looking to try and understand the various relationships.

This participant, and others, felt that one benefit of using 3DVT was its ability to improve the time efficiency of student learning, particularly related to student's 3D understanding of the human body.

Additionally, several participants discussed how 3DVT was used to make time in labs more efficient. One participant used interactive 3D tables in a lab where students rotated through stations, and he explained the time this saved, stating, "And then you'll see there's a little button that says return to start. That's important, because if they hit that button when they leave the table, it's set up for the next group to start." Similarly, another participant describes how the technologies ability to create premade screens improved efficiency in the lab:

> He'll prepare, say for instance when we're doing the pectoral region, he'll prepare screenshots. So, preparing a screenshot is not that trivial in [the 3D application] because you have to know what to get rid of. So, he'll have one image at each depth of the dissection . . . So, they have all these pre-prepared. Things that would take them too much time really to do. So, he does that for every lab he might have five to ten screenshots that they can look at and refer to and rotate and play with.

Like this preclinical faculty member, several participants expressed willingness to put in additional time and work outside of the class in order to prepare materials that would make the most efficient use of limited time with students.

*Create Low Risk Training*

While it is common for students and residents to learn through clinical practice, there are some concerns that it can create unnecessary risk for patients. Two postgraduate participants talked about using 3DVT as an alternative resource to create low risk training environments. One participant discussed the advantages of having residents complete laparoscopic surgical skills training using virtual reality:

> The whole reason I encourage them to do VR is, if nothing else, then you say, "Well, I want you to feel confident when you walk in the operating room that you're going to know your up and down, your left and right, your forward and backwards, because the time to learn is not on somebody's grandmother or mother or brother, the time to learn is before you ever get here."

This participant describes the importance of using the technology to create an environment where residents are able practice skills, and become familiar with tools and operating environments, without risking harm to patients. In this way, the instructor provides a way for them to learn critical skills early on, so that they are able to focus on other components of patient care once they reach the operating room.

*Summary: Filling a Deficiency*

Overall a large number of participants talked about filling what they saw as a deficiency in other methods by using 3DVT to reduce dependence on wet labs, provide alternative visualization, increase accessibility, improve time efficiency, and create low risk training. While some participants talked about replacing other resources entirely, most talked about how they saw 3DVT as supplementary resource to other methods. Several of these participants discussed how using 3DVT allowed them to fill more than one deficiency, such as one who discussed the use of virtual reality to supplement traditional surgical skills labs:

> I think a lot of people that are very negative about VR say, well, that will never replace X, well you're not trying to replace X, you're trying to augment X . . . I think VR gives you that opportunity to do things like that. Exactly like access cadaveric models at home, or to think about practicing skills that you would otherwise have to do a live animal lab to get. It's not

going to totally replace being in the operating room or doing a dissection in a cadaver lab. But it does allow you to get extra reps or allows you to see the model a little bit differently.

This participant felt that the use of virtual reality as a supplemental teaching resource provided the opportunity to fill multiple deficiencies by reducing dependence on wet labs, increasing accessibility, and providing alternative visualizations. Table 4.3 summarizes the subthemes related to how faculty discussed using 3DVT for filling a deficiency.

Table 4.3: Summary of Filling a Deficiency Subthemes

| **Filling a Deficiency** | |
|---|---|
| Reduce dependence on wet labs | The expense, time constraints, and negative perceptions associated with cadaver labs have led some to look for ways to supplement or even replace traditional wet labs. |
| Provide alternative visualization | 3DVT is used when limitations of traditional teaching modalities create difficulty adequately visualizing some areas of complex anatomy. |
| Increase accessibility | The portability and convenience of many 3DVT devices can increase accessibility when other resources may not be easily available when or where the learner needs, such as at home or in the clinic. |
| Improve time efficiency | Time is often limited in the curriculum and faculty must use methods of teaching that allow them to efficiently cover required content within given time constraints. |
| Create low risk training | 3DVT is used to create an environment where learners can practice skills without risking harm to patients. |

**Improving Visualization**

The human body is intricate, with multiple layers and complex pathways, and students must develop a detailed understanding of human structure. Faculty provide students with a variety of visualization tools, such as diagrams, medical imaging, and cadavers, to help them build their understanding of the human body. In discussing 3DVT faculty participants talked about a range of functionalities provided by the technology that they hoped would provide better imagery for helping students visualize complexities of the human form. Specifically, faculty talked about using a) image modification, b) animations, c) rotation, and d) 3D perspective for improving visualization of anatomy.

*Image Modification*

Many of the participants talked about using various functions of the 3DVT that allowed them to alter visualizations, thereby creating an image ideally suited for a particular teaching task. These participants talked about how modifying the 3D images by adding or removing structures, changing image coloration or transparency, and isolating specific structures provided the necessary visualizations for helping students gain an understanding of a given topic. One participant described their perspective of using image modification as a way to improve student visualization:

> The idea that you can take things away and add things back, and make things transparent, so you can see what's underneath it. Or understand the path of a nerve all the way down. It just, I think it helps. Yeah, because a lot of the time in lab we're also working very regionally and then you expect them to then be able to, you know, put it all together. And something like head and neck especially is hard. So, it helps to have something that you can refer to that can be systemic rather than regional. So, for instance, you could just look at the muscles and the arteries and understand, you know, the whole arterial pathway of the limbs.

This participant expressed how 3D visualizations were used as an adjunct to lab teaching because they allowed students to modify images to view isolated systemic structures. They felt that image modification allowed students to visualize nerves and arteries in a way that helped them build their understanding of these pathways. Additionally, this participant, and others, described how they felt the use of transparency helps students visualize the relationships between various anatomical structures.

Similarly, other participants talked about how they felt the ability to add or remove structures from 3D images aided student's ability to visualize relationships and build their spatial understanding. One participant explained their perception of why the ability to remove structures helps students build spatial understanding:

> If they know how things are spatially arranged, they will be better able to know, "oh, I have to go underneath that, then I find this vessel." Or, "this nerve is sandwiched here because of whatever." And three-dimensionality is helpful if you have an application that does that for you, right, because it will constantly reiterate those and you can go through like a puzzle from skin to bone and take layer by layer by layer off and really start building that map just by repetition.

While several participants referred to this type of virtual dissection using 3DVT, another described having students successively add structures to the models:

> If they hit step one, the table will show a skeleton, basically. And then we started adding the lateral wall muscles and ligaments, and this done in a stepwise manner . . . So, what we're doing is, stepwise, I'm sort of building the human, rather than taking it away. It's the opposite approach of what you do in dissection; I'm sort of building things, because I think it's easier to see it, and you can see the relationship of things a little easier when you do that.

Whether using the 3DVT for building or dissecting, faculty participants felt the ability to successively add or remove structures was beneficial for helping students visualize important relationships.

*Animations*

An important component of teaching anatomy involves helping students think about how the structures they learn relate to movement of the body. A few of the participants described using animations to help students better visualize some of these movements. For example, one participant described demonstrating muscle actions, stating, "you can go through and if you're looking at the shoulder, you can do animations to see how the muscles move things." Another explained how a colleague used animations:

> So, the faculty member that does more musculoskeletal, he has had some good success with some of those animations showing muscle actions and has spoken very highly about how the students better appreciate some of those movements and neural lesions that might affect those movements as a result.

This participant describes the use of animations to not only help students understand muscle movement, but also begin to think about how impairment might change these movements.

*Rotation*

While some resources provide images and diagrams that can only be viewed from a single perspective, faculty frequently discussed using 3DVT that provided the ability to rotate visualizations. Participants described using rotation to show the course of structures, such as one who commented "to understand the circumflex scapular artery, how it gets to the back, you know, that's kind of a cool thing to be able to look at to sort of turn the scapula, to be able to see." These participants described using rotation to help students visualize the course of structures with complex pathways, such as muscles that wrap around bones, tortuous blood vessels, or branching bronchi.

Other participants described using rotation to help students visualize the orientation of structures and build their understanding of structure relationships. One participant described using rotation to demonstrate the heart for preclinical students. This participant explained how they use rotation to demonstrate the orientation of valves, helping students connect this understanding to the clinical practice of auscultation. Another described using rotation of 3D reconstructions for teaching imaging interpretation in a nuclear medicine residency program:

> Well, I just gave a lecture on lung imaging, and one of the areas that is commonly mistaken for an abnormality is the back part of the lung . . . And I was pointing out to the residents that it's really not a problem within the lung, but it's actually the scapula that's sitting over it preventing some of the radiation from going through. So, what I did was I created one of those 3D reconstructions of the chest and rotated it to that particular projection, and put a projection of my typical lung scan that has that defect in it next to it, so they could see very clearly where that defect corresponds to the scapula. And once they see that, then they understand that that defect is not likely to be a problem with the lung, it’s really more likely to be because of the scapula.

By showing the corresponding rotated 3D image next to the 2D medical image, this participant helped students see how the relationships of the structures in an area were related to the appearance of these structures in the scan.

*3D Perspective*

Computer-generated images can be programmed with the necessary visual depth cues that create 3D perspective. Faculty described how using 3DVT provides students with images containing depth and allows structures to be viewed in a 3D perspective. One participant described their viewpoint on using images that provide 3D perspective:

> I think the biggest benefit is some people really struggle with seeing three-dimensional images. So for me, looking at a flat piece of paper with an anatomical design, I can somewhat make the flip instantly into what it's going to look like 3D, so I can sort of look at it, and I sort of know where things are going. For some folks, that three-dimensional projection is not as easy. So, I think having some sort of 3D projectional image that you can work with [helps].

This participant uses 3DVT to provide visualizations with 3D perspective with the hope that it will help preclinical students begin to build their 3D understanding of anatomy. Similarly, another participant described how they believe 3D images improve visualization:

> It's an additional advantage for them to be able to understand the perception of a 3D image. Basically, you're looking at it in a 3D perspective and that makes a lot of difference. Like if I talk to you about 2D ultrasound, it is just like real time ultrasound, you can only see it on a two dimensional view, but if it's 3D it's got a better depth and we will understand the very accurate position of the various organs related to each other.

This participant describes their view that the depth of a 3D image plays an important role in helping students learn relationships of structures to one another.

*Summary: Improving Visualization*

Overall, faculty described using 3DVT for improving visualization of the human body in a multitude of ways. One participant summarizes what improved visualization from use of 3DVT means for her ophthalmology residents:

> Think of this as a 3D book—it's just another book. And given that in anatomy it's all visual, everything is about the relative size, relative positioning of structures, so why are we trying to explain it in words? Let's enhance the words, the descriptions that have been brought down

> from years and ages, let's enhance it with not just the diagrams or just a cross section of something, they're flat, and give the students something tangible, something that they can look at [with] 360-degree rotation, and they can hide and, unhide things. And they can you know, and you can color things up to focus on a particular structure. There are so many things you can do. You're just bringing another level of understanding like the concept clarity. So one is that the books provide information, and I feel the 3D anatomy provides concept clarity.

This participant described how they used multiple functionalities of 3DVT for trying to improve visualization, including image modification, rotation, and 3D perspective. Participants described several ways they use 3DVT to try to improve visualization of structures for students, and Table 4.4 provides a summary of these subthemes.

Table 4.4: Summary of Improving Visualization Subthemes

| **Improving Visualization** | |
|---|---|
| Image modification | Faculty use technologies that allow for the alteration of visualizations by providing the ability to add or remove specific structures, change image coloration and transparency, or isolate specific organ systems. |
| Animations | Faculty use animations to help students visualize movements of the body such as muscle movements, helping to link form and function. |
| Rotation | Faculty use rotation of structures to help students visualize structure orientation, relationships, and pathways. |
| 3D perspective | Faculty use 3DVT because the visual depth cues allow structures to be viewed in a 3D perspective. |

**Customizing Learning Experiences**

The choice of an instructional resource can influence certain aspects of the curriculum, such as the content or sequence, and a number of faculty participants discussed how their use of 3DVT allowed them to customize certain learning experiences. By altering the information that was presented using 3DVT or changing how the technology was used for teaching, faculty created learning experiences tailored for their specific purposes. Specifically, participants talked about customizing learning experiences by using 3DVT to a) create focused content, b) demonstrate pathologies, and c) integrate topics. Faculty described how this use of 3DVT allowed them to customize aspects such as the content, sequence, and instructional processes of the curriculum.

*Create Focused Content*

A number of participants described creating focused content by utilizing the ability of the technology to design premade materials and lessons tailored for what they want students to learn. One participant described linking 3D models to a lesson plan that walks students through each station during their lab sessions:

> But the screen when you look at it, it’s divided into sections: a 3D body, and on the side you can put your lesson plan. So, that lesson plan, then controls both the three-dimensional window, and the axial CT like cuts, so that I can take the educational part of it, [and] control what's on the rest of it.

This participant describes linking lesson plans with the 3D images on the screens, so students move through predesigned activities, and learn specific content presented. This premade design allows the participant to then customize the content, sequence and instructional process associated with the lab activities.

Other participants described similar ways of using 3DVT for creating focused content to customize curricular elements. Some of these participants created lessons plans using the 3DVT to customize teaching sessions, while others labeled structures to focus student attention on important content. One participant describes focusing content based on surgical procedures:

> We actually look at a textbook of surgery, we look at the anatomy that you go through to get to your objective, and then we create a dissection model on the table that allows them to sequentially learn their surgical approach doing 3D anatomy.

This participant describes customizing not only content, but also the sequence so that students learn the anatomy based on the order they would see the structures during a given procedure. While many participants used 3DVT for creating focused content, one described how the technology did not provide this ability:

> The program is very comprehensive in the number of structures that it offers. It's also very detailed in giving you the anatomy sort of textbook material, which we don't really cover a lot of the verbiage behind in our course. What I think would be more applicable for the students is if we could limit the content of structures to match our structure list so that there would be a direct correlation, and so that when they click on a structure that's esoteric to that particular thing, they wouldn't be wasting time with it.

This participant expressed that the ability to create focused content likely would have been beneficial for students, but the specific 3DVT being used would not allow for this type of customization.

*Demonstrate Pathologies*

It is important for students to relate normal anatomy to abnormal anatomy which might be seen in the clinic, and a number of participants discussed using 3DVT to demonstrate relevant pathologies. By selecting or creating images with specific pathologies faculty customize lesson plans that cover certain clinical conditions, or help students see the clinical relevance of anatomical structures they are learning. One participant describes the types of pathologies available in the software:

> There were one or two files in the program which showed aortic aneurysms and there's one with a tumor on one of the bronchi, and even renal carcinoma, big tumors of the kidney, there was one of that. And the female there was this fibroid in the uterus, that was also one.

This participant uses preexisting images in the software to demonstrate various pathologies to preclinical students.

Another participant describes how they are able to generate 3D images with specific examples of pathologies:

> The students here are lucky in the sense that I get copies of CAT scans that I used when I was in practice, of my patients. And I take them, and I anonymize them. I can remove the data from them, so they can't see the patient's name, and I can import those CAT scans into [the 3D program] . . . I can use all of these tools and technology to give a lecture on clinical relevance by showing pathology.

Because a wide range of patient scans can be loaded into the program this participant customizes lectures on clinical relevance by selecting examples of pathologies to show students relevant abnormal anatomy. Finally, a postgraduate participant describes another way to generate customized images for demonstrating pathology:

> Normally they learn by examining each other in a big classroom. And most, 90%, 99%, of these exams are normal. But then on the virtual patient, we give them, we build in a pathology, so they get to see and practice what that would look like. And then the anatomical reason behind that abnormal exam, they can switch over to anatomy and figure it out from there. So, there is a correlation, anatomical and clinical correlation at their fingertips.

This participant, and one other, describe how the computer programming used to create 3D visualizations allows for specific pathologies to be added into the images.

Whether pathologies preexist in the software, are loaded in, or are custom programmed, faculty use the ability to demonstrate these pathologies to customize teaching of clinical relevance.

*Integrate Topics*

Several of the participants talked about using 3DVT for integration, describing how they used it to join multiple aspects of the curriculum. Faculty participants explained how 3DVT provides a resource that can be customized to include elements from other areas of the curriculum. One participant describes using the technology to add content from other areas of the preclinical curriculum:

> The other side of this table is that we can also put histology into this . . . We can call this thing up on the other side of this table which gives us the CTs, the MRIs, the ultrasounds, plus, the histology. And I can cut and paste that stuff, take it out move into what I'm doing pretty easily. So that we've looked at this table as a way of sort of joining multiple aspects of their curriculum.

This participant is using the 3DVT for horizontal integration by adding in material, e.g. histology slides, from other preclinical content areas previously taught outside of gross anatomy. Similarly, many participants use 3DVT for vertical integration by adding clinical content into preclinical anatomy courses. For example, one participant describes providing students with 3D scans of their donors:

> As we, and other schools, are moving to integrate anatomy, not just preclinical, but in those clinical years as well, it's that where that fits is pretty important. We think that the student, the preclinical student needs to see anatomy in the clinical context. So, what we mean by that is we scan our donors. And so even from the beginning, when they're dissecting, we're encouraging them to connect the anatomy that they're putting their hands on with the CTs that they have available for those donors.

This participant used 3DVT to integrate medical imaging into the anatomy lab so that students were introduced to clinically relevant content early on in their learning.

*Summary: Customizing Learning Experiences*

Faculty talked about using 3DVT for customizing learning experiences in a variety of ways. Participants talked about customizing aspects of the content, sequence, and instructional processes by using 3DVT for creating focused content, demonstrating pathologies, and integrating topics. These participants described how their use of 3DVT to customize experiences was done with a goal of focusing attention on relevant content, demonstrating links between normal and abnormal anatomy, or providing clinical relevance of the content being learned. Table 4.5 provides a summary of the subthemes related to customizing learning experiences.

Table 4.5: Summary of Customizing Learning Experiences Subthemes

| Customizing Learning Experiences | |
|---|---|
| Create focused content | Faculty use of technology to design premade content tailored for what they want students to learn. |
| Demonstrate pathologies | Using the technology to show relevant pathologies by loading patient specific scans, using preexisting images, or otherwise adding pathologies into visualizations. |
| Integrate topics | Use of the technology to help join multiple aspects of the curriculum allowing for horizontal or vertical integration. |

**Enhancing Learning Experiences**

With limited time in the curriculum, faculty must make the most out of student learning experiences, both in the classroom and at home. Many participants talked about how they hoped to enhance learning experiences by using 3DVT to a) link visualizations and course elements, b) provide repetition, c) engage students, and d) deliver team training. These participants described using 3DVT because they felt it could improve the quality of education by offering what they perceived as an efficient and effective learning resource.

*Link Visualizations & Course Elements*

Faculty use 3DVT to provide students with 3D models and images, and many of the participants talked about how they link these visualizations to other course elements. These participants discussed how they connect the images to other components of the curriculum such as subject matter, additional resources, or assessment items. For example, one participant describes how he connects the 3D models they work through in lab to questions:

> The students basically just work through the steps. And with those steps are embedded questions. You know, to pinpoint the things I want them to learn as they go along.

By connecting the 3D visualizations with questions about anatomy seen in the images, this participant links the images with formative assessment items to help students check their understanding of material.

Other participants talked about linking 3D visualizations to additional instructional resources. For example, one participant described digitalizing and linking a textbook to interactive tables with 3D models:

> So rather than studying the anatomy textbook, while you're reading how to do the operation, you're able to actually remove the structures and do the operation while you're reading how to do it . . . And for the resident rather than telling them to read to Te Linde's *Operative Gynecology*, they read Te Linde's, but then they also can go to the anatomic reinforcement of what the hysterectomy is. So, when they say you're going to put a

> clamp on the broad ligament, they can just go to broad ligament and see where that is, where it originates and what the vessels are, and the at risk or fragile structures that are nearby.

While this participant talks about linking 3D models to a textbook, other participants described linking visualizations to resources such as medical image libraries, clinical correlation videos, or various teaching modules. Finally, several participants described linking visualizations with content. One participant described how visualizations were linked to subject matter for a preclinical course:

> If they wanted to study structures, it has the ability that you can point and click, so if you point on a structure it will tell you the name, what it does, structures that are in relationship to it. So, it's like a virtual textbook that provides you with some 3D imaging.

In this case, when students clicked on the 3D images, additional subject matter was presented, linking the visualizations to course content. Several participants talked about providing students with this type of comprehensive resource by linking visualizations to content such as structure names, clinical correlates, and medical images.

*Provide Repetition*

The acquisition of knowledge and skills may be enhanced by repetition, and because 3DVT can be easily reset, faculty use it as a resource to provide students with repetition in their learning. One participant describes using repetition to help residents learn surgical anatomy:

> As you know, if you do a cadaver dissection, you only get to do it once. And then you have to study it and learn it, and then you get into the operating room. With this, you could go back and forth through the surgery up and down from inside to outside as many times as you needed to get that same anatomic core knowledge prior to going into the operating room.

This participant explains how the 3DVT can be easily reset, allowing students to repeat the process of examining the anatomy in the sequence it is found during a procedure. The participant expressed hope that this process helps students build their anatomical knowledge related to the operation through repetition. Another postgraduate participant describes giving ophthalmology residents practice with clinical eye exams:

> And the feedback has been really good because again, they got practice, they practice the same thing in different ways, multiple times, they get anatomic and clinical correlation, and they get to see abnormal exams . . . So now they're better prepared for their clinical rotations, when they go and see, they'll have a better idea of how to examine and how to recognize and the why behind the abnormality.

By providing a chance to repeat the process of the virtual eye exams this participant believes students will build an understanding of anatomy associated with the eye and develop their ability to perform eye exams. Like the participants in the two examples given here, several participants described how they hope 3DVT will help students build their knowledge and skills through repetition.

*Engage Students*

Faculty participants also described how they hoped to enhance learning experiences by using 3DVT to engage students in learning activities. These participants described using 3DVT because they felt it could increase student interest and promote student involvement. One participant described using virtual reality for making surgical anatomy education interactive:

> It's sort of like hands on anatomy. If I teach a medical student or an intern about Calot’s triangle, or where's the cystic duct relative to the common bile duct, it's one thing for me to draw it on a chalkboard. It's another thing for me to put them into a VR simulator, and say okay, now you dissect out the structures, and you name to me, what's the cystic duct,

> what's the artery, what's the common bile duct, and what's the importance of this thing that we keep calling Calot’s triangle?

This participant describes getting students engaged in the learning process by having them actively dissect and interact with structures using a simulator. While several participants talk about engaging students through the interactivity provided by the 3DVT, others also mention using 3DVT to increase student interest. One participant described engaging students in learning through the use of 3DVT:

> If you can just come into a classroom where people are using the table compared to a classroom where you're giving a lecture, they are so much more engaged . . . That to me is what's so fascinating about this tool is that people think it's so cool to use it.

This participant described their hope to capitalize on student interest in novel technologies to not only improve current learning, but also promote future learning. Participants who discussed engaging students talked about getting them more involved in their learning by capitalizing on student interest in using 3DVT and by promoting student interaction with the 3DVT.

*Deliver Team Training*

Finally, two participants talked about using 3DVT to deliver team training. For example, one participant described how virtual reality can be used with multiple people:

> And now we're starting to see even more complex things like VR team training where you have multiple people in the same VR environment. And now it's not just about training the individual, it's about training the individual to function within a team, which is how we deliver health care.

This participant described how multiple people operating in the same VR environment can be used with the goal of helping learners develop teamwork skills. Similarly, another participant described using 3DVT to bring multiple people together in a learning activity:

> Next, we are stepping into interprofessional learning . . . So, some things like neurosurgery, ENT, ophthalmology, neurology, that could all get together and discuss this. So interprofessional in that regard, like you can have a discussion with, instead of just talking, you have something that you can interact with it, you can turn things around, you can zoom in, zoom out, you know, how it just gives you capability, and just ideas off of different approaches, understanding the anatomy, and discussing different surgical approaches. That we are planning later this year.

This participant described using 3DVT to facilitate discussions between individuals from different specialties in order to promote interprofessional learning. These participants described how 3DVT is beginning to allow for team training, providing another way for faculty to enhance learning experiences.

*Summary: Enhancing Learning Experiences*

Participants talked about the goal of using 3DVT to enhance learning experiences in a number of ways. They described linking 3D visualizations to other elements of the curriculum to incorporate additional questions, subject matter, and resources. Faculty also discussed using 3DVT for providing repetition, engaging students, and conducting team training. The goal of these participants was to use 3DVT for promoting deeper learning, helping students assess their understanding, aiding in the development of new skills, and increasing student involvement in learning activities. Table 4.6 provides a summary of the subthemes related to how faculty use 3DVT in a way they feel enhances learning experiences.

**Summary: Instructional Resources**

Thematic analysis generated four major themes that describe how faculty use 3DVT as an instructional resource. The majority of participants talked about filling what they saw as a deficiency in other methods by using 3DVT as a resource. These

Table 4.6: Summary of Enhancing Learning Experiences Subthemes

| Enhancing Learning Experiences | |
|---|---|
| Link visualizations & course elements | Some software programs have the ability to directly link aspects of the 3D visualizations to additional components of the curriculum such as subject matter, additional resources, and assessment items. |
| Provide repetition | Technology can be reset to allow for easy repetition of activities. |
| Engage students | The technology is used to engage students in learning. |
| Deliver team training | Technology is utilized to bring multiple users together so they can interact for team training. |

participants talked about using 3DVT to a) replace or supplement the use of wet labs, b) provide alternative visualization when areas of anatomy were difficult to see, c) increase accessibility when other methods were not readily available, d) improve time efficiency of activities and learning, and e) create low risk training to reduce risk to patients. Faculty participants also described how multiple functionalities of 3DVT allowed them to use 3DVT as a resource for improving visualization. These participants described using image modification, animations, rotation, and 3D perspective to provide students with ways to visualize layers, movement, and complex pathways, so that they could develop a detailed understanding of the human body.

A number of faculty participants discussed how altering the information that was presented using 3DVTs or changing how the technology was used for teaching allowed them to create learning experiences tailored for their specific purposes. These participants described using 3DVT to customize learning experiences by a) creating focused content to specify subject matter or processes, b) demonstrating pathologies to provide relevant clinical context, and c) integrating topics to incorporate other subjects or clinical content. Finally, participants discussed how using 3DVT was perceived to enhance learning experiences by a) linking visualizations to course elements such as content, resources, and assessment items, b) providing repetition for students to build skills and knowledge, c) engaging students to increase student involvement and interest, and e) conducting team training. Figure 4.2 provides a diagram illustrating the themes and subthemes which describe how faculty use 3DVT as an instructional resource.

*Purposes*

Another curricular element explored in relation to faculty use of 3DVT was purposes. Lattuca and Stark (2011) define purposes as the "knowledge, skills, and attitudes to be learned" (p. 4). Faculty make important decisions about the purposes of a curriculum, and the intended outcomes they have for 3DVT use reflect their views about the goals of education. Faculty use of 3DVT was examined in relation to purposes by exploring the knowledge, skills, and attitudes faculty hoped students gained from the curriculum, particularly from the use of 3DVT. In exploring this academic plan element, the themes generated from analysis were used to answer the following research sub-question:

- What do faculty see as the purpose of anatomy education at their respective level and how do they use 3DVT to try to achieve these goals?

Thematic analysis resulted in ten subthemes representing the knowledge, skills, and attitudes faculty hoped students would learn from their program and through the use of 3DVT. These subthemes were grouped into three major themes describing what faculty see as the purpose of education at their level: 1) Foundational Knowledge and

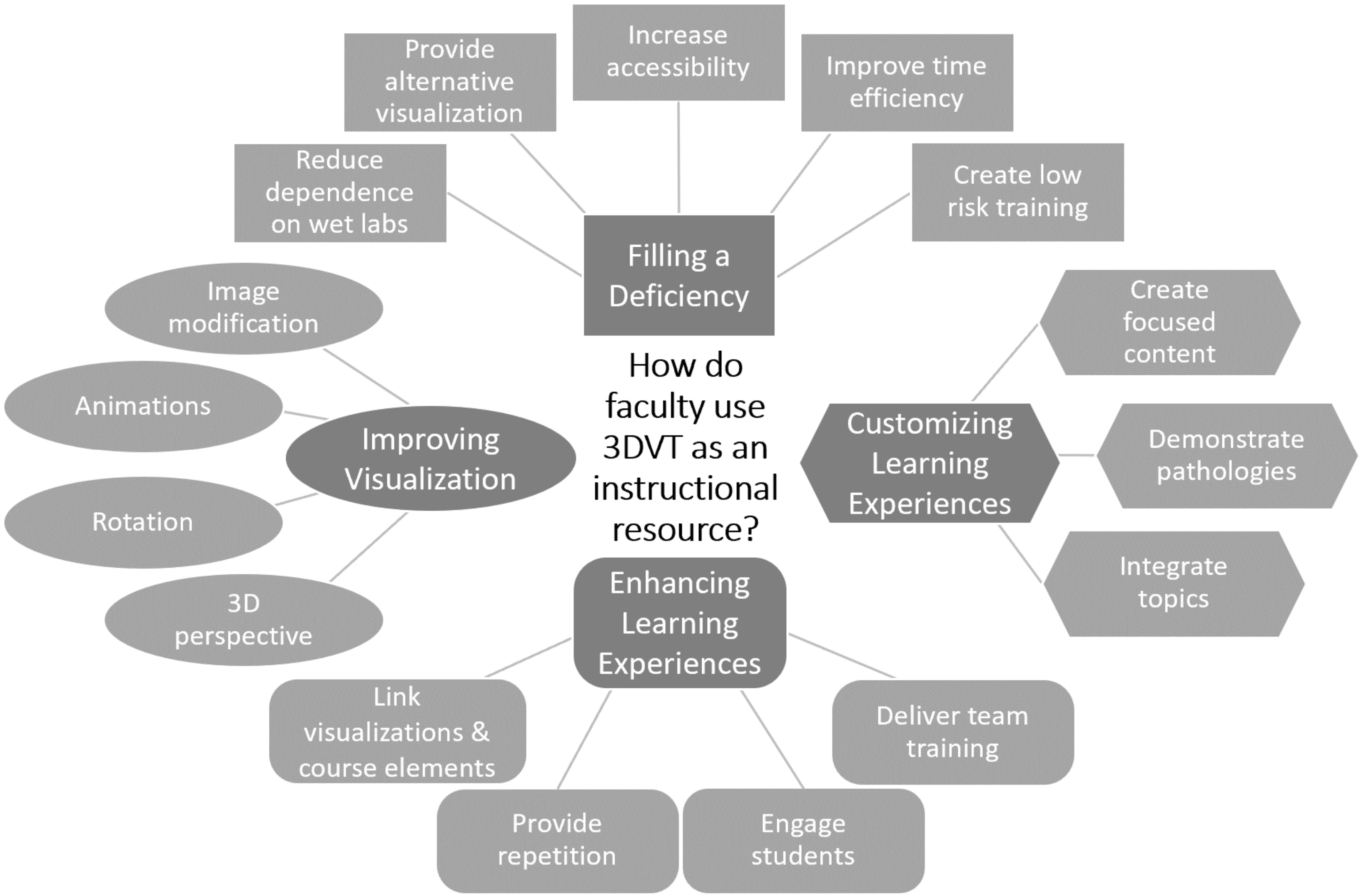



Figure 4.2: Themes and Subthemes of 3DVT Use Related to Instructional Resources

Skills, 2) Clinical Knowledge and Skills, and 3) Preparing for Work as a Physician. Participant quotes were then examined to find examples of faculty describing how they use 3DVT to try to achieve a particular goal. These quotes were used to link subthemes of 3DVT use as an instructional resource to subthemes of purposes to demonstrate how faculty describe using 3DVT to work towards achieving educational goals.

The following sections discuss each of the three themes for purposes, along with their related subthemes. This discussion of themes and subthemes explores what faculty see as the purpose of education in their course or program. Additionally, the discussion of each subtheme includes a diagram with quotes illustrating the links that were found between that subtheme for purpose and the subthemes for use of 3DVT as an instructional resource. These links describe how faculty use 3DVT to try to achieve certain educational goals of the curriculum. A final section summarizes the themes related to purposes.

**Foundational Knowledge and Skills**

A strong understanding of anatomy forms an important part of the underlying base on which students build their medical knowledge. Many of the faculty participants described foundational knowledge and skills in anatomy when discussing the purpose of education in their course or program. Faculty who defined foundational knowledge and skills as a purpose of education discussed intended learning outcomes related to a) fundamental understanding, b) form and function, and c) 3D understanding. These participants described their hope that using 3DVT would help students obtain anatomical knowledge and skills which would build or strengthen their medical science foundation.

*Fundamental Understanding*

A majority of faculty participants discussed the importance of ensuring students achieve a strong fundamental understanding of anatomy during their course or program. These participants had goals related to the development of student's core understanding of human form, such as the ability to identify structures, knowledge about the pathways of various structures, and the layout of structures in the body. One participant described using 3DVT in a preclinical course to help build student skills in structure identification, stating "part of our course is structure identification, and identification of structures in relationship to one another. So, obviously, I was hoping initially it would help with just their ability to find structures." A number of participants also discussed core anatomy knowledge taught during the preclinical curriculum, while others discussed covering fundamental topics during clerkships and residency programs. For example, when asked about the primary goals of education in surgical residency programs, one participant explained:

> Sort of the party lines from the board of surgery, obviously, is that we're trying to train physicians to do surgery . . . And that involves everything, ranging from the fundamental knowledge base component, cognitive knowledge, I guess is how most people think about it, to anatomical knowledge about what's actually happening.

This participant described the necessity of core anatomical knowledge when training surgical residents, explaining their view that fundamental understanding is an important purpose of education at the postgraduate level.

Participants who described fundamental understanding of anatomy as a purpose of education discussed using 3DVT in a variety of ways to try to achieve this goal. Based on participant quotes select subthemes related to use of 3DVT as an instructional resource were linked to the purpose of fundamental understanding. Figure 4.3 illustrates how faculty described using 3DVT as an instructional resource to provide students with fundamental understanding and includes example quotations demonstrating the links between subthemes. Participants described teaching core anatomy topics by using 3DVT to create focused content, integrate topics, link visualizations and course elements, provide alternative visualization, and increase accessibility. Participants also described how they used the rotation and image modification provided by 3DVT because they felt it could help students develop certain fundamental anatomical knowledge and skills.

*Form and Function*

In addition to fundamental understanding, faculty participants also discussed educational goals related to student understanding of form and function. These participants discussed how building a student's ability to connect human structure with how things work represents additional foundational knowledge and skills that future practitioners must develop. One participant describes using virtual reality eye models to help students connect structure and function:

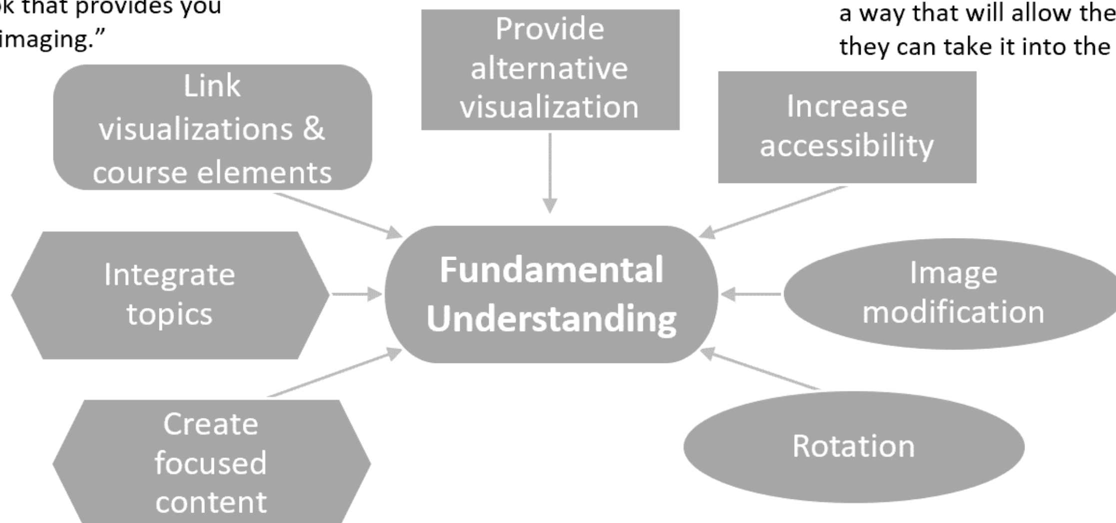
> Ocular motility, that's cranial nerves three, four, and six. People are trying to memorize mnemonics and this and that, but with the simulator, they just get it. They see where the muscle sits, which direction it pulls, and it makes total sense why its action is what it is.

“It also has a cadaveric quiz as part of the package. So if they wanted to study structures, it has the ability that you can point and click, so if you point on a structure it will tell you the name, what it does, structures that are in relationship to it. So it's like a virtual textbook that provides you with some 3D imaging.”

“You know, the perineum would be another area where while they definitely have a better understanding of superficial and deep pouch, everybody's not favorite, but certainly one that we discuss all the time, and they definitely have a better appreciation for it now. Again, things that in the fixed tissue are hard to see.”

“I don't expect them to remember everything. But I expect them to be able to come back and look at this stuff and review things before they go into surgery. Or if they have a kid with congenital heart disease, they ought to be able to go back and look at this stuff. So that what I'm trying to do is find a way that will allow them to do that. So they can take it into the clinical years.”

“But we can call this thing up on the other side of this table which gives us the CTs, the MRIs, the ultrasounds, plus, the histology. And I can cut and paste that stuff, take it out move into what I'm doing pretty easily. So that we've looked at this table as a way of sort of joining multiple aspects of their curriculum”




“I then had to work it into our single pass organ-based system curriculum. And what the tables allow me to do is modify things so I can focus in on an organ system of the week.”

“He'll have one image at each depth of the dissection, so he'll show it first with the Pec major intact, then he'll take the pec major off, and maybe it'll show the muscles at first by themselves and then he'll reflect pec minor and then show you know brachial plexus by itself, or the arteries by themselves. So they have all these sort of pre prepared.”

“Because understanding, you know the internal and external muscles sort of as, you know, it helps you to understand the obturator internus if you actually can turn it around and see it.”

Figure 4.3: How Faculty Use 3DVT to try to Achieve the Goal of Teaching Fundamental Understanding

Like this participant, several others talked about the importance of helping students appreciate the relationship between the form of a muscle and its associated movements.

While some participants discussed teaching muscle movements or similar structure function relationships, others talked about teaching students how form can be related to dysfunction. One participant describes using the ability to demonstrate the structure of certain arteries to discuss clinical correlations:

> You ask them, okay there's a thrombus in the aorta, why should it get into the superior mesenteric, why can't it get into the inferior mesenteric, or into the celiac trunk. So, you tell them it's almost in line with the aorta, it's got a very acute angle, so a thrombus can easily get into that artery [rather] than any other artery.

This participant describes teaching students to visualize, and appreciate, how the structure of the aorta with its branches is closely related to where a blood clot is most likely to travel. Participants like this feel it is important to teach not only how structure is related to normal function, but also how it is related to why things happen the way they do clinically.

Several of the participants discussed how they use 3DVT as an instructional resource to try and help students build their understanding of anatomical form and function. Figure 4.4 illustrates how faculty described using 3DVT as an instructional resource to provide students with a foundational understanding of form and function, including example quotations demonstrating the links between subthemes. Discussion by these participants demonstrates how faculty use image modification and animations provided by 3DVT for teaching students to connect human structure with how things work and why things happen. These participants discussed how image modification was used to isolate structures so their form could be better appreciated by students, while animations were used with the hope that it would help students better appreciate the movements associated with various muscles.

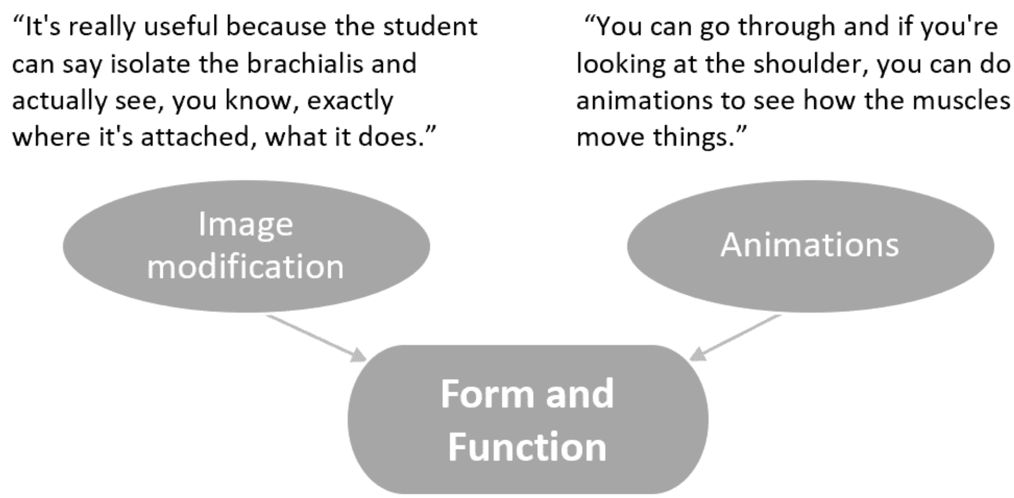



Figure 4.4: How Faculty Use 3DVT to try to Achieve the Goal of Teaching Form and Function

*3D Understanding*

A final area of foundational knowledge and skills talked about by faculty participants was students' 3D understanding of anatomy. The majority of participants talked about how helping students develop a strong visuospatial understanding of the human body was an important purpose of education in their course or program. When asked about the primary goals of education in neurosurgery residency programs one participant stated, "Understanding three-dimensional relationships of structures and how they're related to each other, how we can access them, and how we can safely navigate around the structures." Like this participant, many faculty members expressed the importance of helping students understand the relationships of various structures relative to one another, particularly for dissection or in surgical programs where emphasis is on navigating among various organs, nerves, and vessels.

While many participants discussed developing student understanding of structure relationships, other participants talked about the importance of students' ability to visualize the three-dimensionality of the human body, including structures and their pathways. For example, one participant described their hope that use of 3DVT would help students build visuospatial skills. This participant explained how many students are not able to initially visualize structures in 3D, and so it is important to help students develop this skill when studying anatomy so that they can better visualize structures and their pathways. Another participant explained the type of 3D understanding they hoped students would take away from 3DVT use:

> I hope they have a better comfort level with the three-dimensionality of the body . . . relatively few students become surgeons, maybe half do, but the point is the other half is never going to see the inside of the body again. But they need to have that understanding still, a good understanding of how the body is arranged, because it's pertinent to every specialty.

This participant explains how one goal of their preclinical anatomy course is to provide students with a strong understanding of the 3D arrangement of the body because it provides important foundational knowledge in any field of practice.

Participants who viewed 3D understanding of anatomy as an important part of students' foundational knowledge and skills discussed using 3DVT in a variety of ways to try to achieve this goal. Based on participant quotes select subthemes related to use of

3DVT as an instructional resource were linked to the purpose of 3D understanding. Participants explained how they hoped to develop students' 3D understanding by using 3DVT to provide repetition, link visualizations and course elements, provide alternative visualization, and improve time efficiency. Participants also described using the image modification, rotation, and 3D perspective provided by the 3DVT to try and help students develop their visuospatial understanding of the human structure. Figure 4.5 includes quotes that illustrate how faculty described using 3DVT as an instructional resource for the goal of providing students with 3D understanding.

*Summary: Foundational Knowledge and Skills*

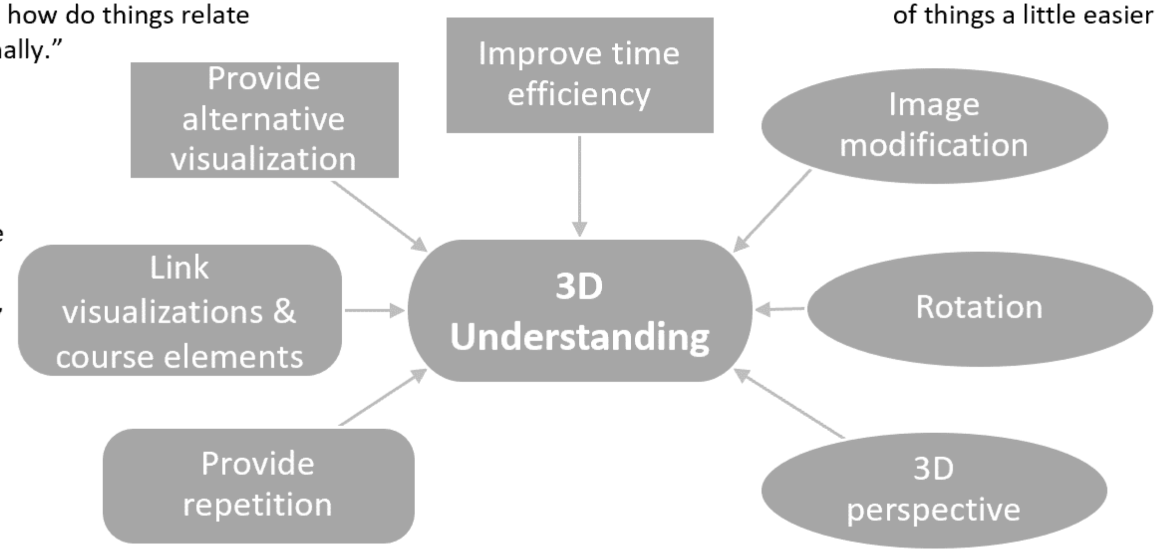
In summary, participants discussed learning outcomes in several areas related to the development of students' foundational knowledge and skills in anatomy. For fundamental understanding, participants described core anatomical understanding such as knowledge of structures, pathways, and the basic layout of the human body. Several participants emphasized goals related to helping students link form and function, such as normal structure function relationships, or the link between form and clinical dysfunction. Finally, most participants described a need to help students gain a 3D understanding of anatomy, including the development of visuospatial skills related to picturing anatomical structures and understanding structural relationships. Table 4.7 provides a summary of these subthemes related to the purpose of providing students with foundational knowledge and skills. Participants described a multitude of ways they use 3DVT for trying to achieve each of these educational goals (Figures 4.3–4.5), largely for developing students fundamental and 3D understanding of anatomy.

"They have a video resource that sort of videos how the dissection should go for them...I just wanted something with a little more 3D projection to it, since we lack that on campus. And that's sometimes an area where students really struggle is how do things relate three dimensionally."

"Understanding three-dimensional relationships of structures ...The 3D anatomy of the nervous system is very complicated. Therefore, anything that assists with understanding these relationships without going to the cadaver lab and spending many hours there would be helpful."

"So, what we're doing is step wise, so I'm sort of building the human, rather than taking it away. It's the opposite approach of what you do in dissection, I'm sort of building things, because I think it's easier to see it, and you can see the relationship of things a little easier when you do that."

"It has the ability that you can point and click, so if you point on a structure it will tell you the name, what it does, structures that are in relationship to it. So it's like a virtual textbook that provides you with some 3D imaging




"If I'm looking at the origin course, branches, termination and relationships of the anterior interosseous artery...not every 2D image that you see in an atlas will give you all of that information. Whereas if you have it in 3D, you can kind of spin it and look at it from different angles, and then understand where all those relationships are."

"If they know how things are spatially arranged, they will be better able to know, oh, I have to go underneath that, then I find this vessel, or this nerve...And three dimensionality is helpful if you have an application that does that for you, because it will constantly reiterate those and you can go through like a puzzle from skin to bone and take layer by layer by layer off and really start building that map just by repetition."

"It's an additional advantage for them to be able to understand the perception of a 3D image...you're looking at it in a 3D perspective and that makes a lot of difference. Like if I talk to you about 2D ultrasound, it is just like real time ultrasound you can only see it on a two dimensional view, but if it's a 3D it's got a better depth and we will understand the very accurate position of the various organs related to each other"

Figure 4.5: How Faculty Use 3DVT to try to Achieve the Goal of Teaching 3D Understanding

Table 4.7: Summary of Foundational Knowledge & Skills Subthemes

| Foundational Knowledge & Skills | |
|---|---|
| Fundamental understanding | A core understanding of human form that creates a foundation of knowledge to build on. |
| Form and function | An ability to connect human structure with how things work and why things happen. |
| 3D understanding | A strong visuospatial understanding of the human structure, how the body is arranged, and the three-dimensional relationships of structures. |

### Clinical Knowledge and Skills

In addition to a strong foundational understanding of science, physicians in training must also develop the knowledge and skills needed to help patients in health care settings. When discussing the purpose of education in their program many of the faculty participants described learning outcomes related to clinical knowledge and skills. Clinical knowledge and skills discussed by faculty included learning outcomes related to a) clinical relevance, b) imaging interpretation, c) anatomy of procedures, and d) diagnosis and disease management. Participants also described their perceptions of how 3DVT was used in the curriculum to help students develop knowledge and skills in these important areas so that they were better prepared to deliver effective patient care.

#### *Clinical Relevance*

Many participants emphasized clinical relevance and discussed how they feel helping students see anatomy within the context of clinical settings is an important purpose of the curriculum. For example, one faculty member described the use of case studies in a 3D imaging lab for a preclinical anatomy course, “The virtual lab is used mostly for cross-sections, and to teach them the clinical relevance behind any of the pathology that we see on these CAT scans or MRs." This participant uses 3DVT to show pathologies because they believe this will help students connect the anatomy they are learning to real world clinical scenarios. Another participant described why teaching clinical relevance is important:

> I think if we moved it into some clinical applications, it would help the students see relevance . . . anatomy is a little bit like learning a roadmap. But if you don't have a destination a roadmap is a really boring thing to study. So, if we could tie into those electronic resources and clinically relevant material . . . that somewhat seems like the next phase in developing these learning aids, as it's not just a matter of learning the roadmap of anatomy, but then learning the clinical relevance of anatomy as well.

This faculty member, and others, explain that by relating structures being studied to clinical problems they hope learners can see the applicability of anatomy and the meaning of the content.

Participants who discussed the value of illustrating clinical relevance described using 3DVT in a variety of ways to try to achieve this goal. Based on participant quotes select subthemes related to use of 3DVT as an instructional resource were linked to the purpose of clinical relevance. Figure 4.6 illustrates how faculty described using 3DVT as an instructional resource for teaching the clinical relevance of anatomy being learned. Participants described helping students see the clinical relevance of anatomy by using 3DVT to link visualizations and course elements, integrate topics, and demonstrate pathologies. Participants also described using the animations provided by the 3DVT to provide clinically based content.

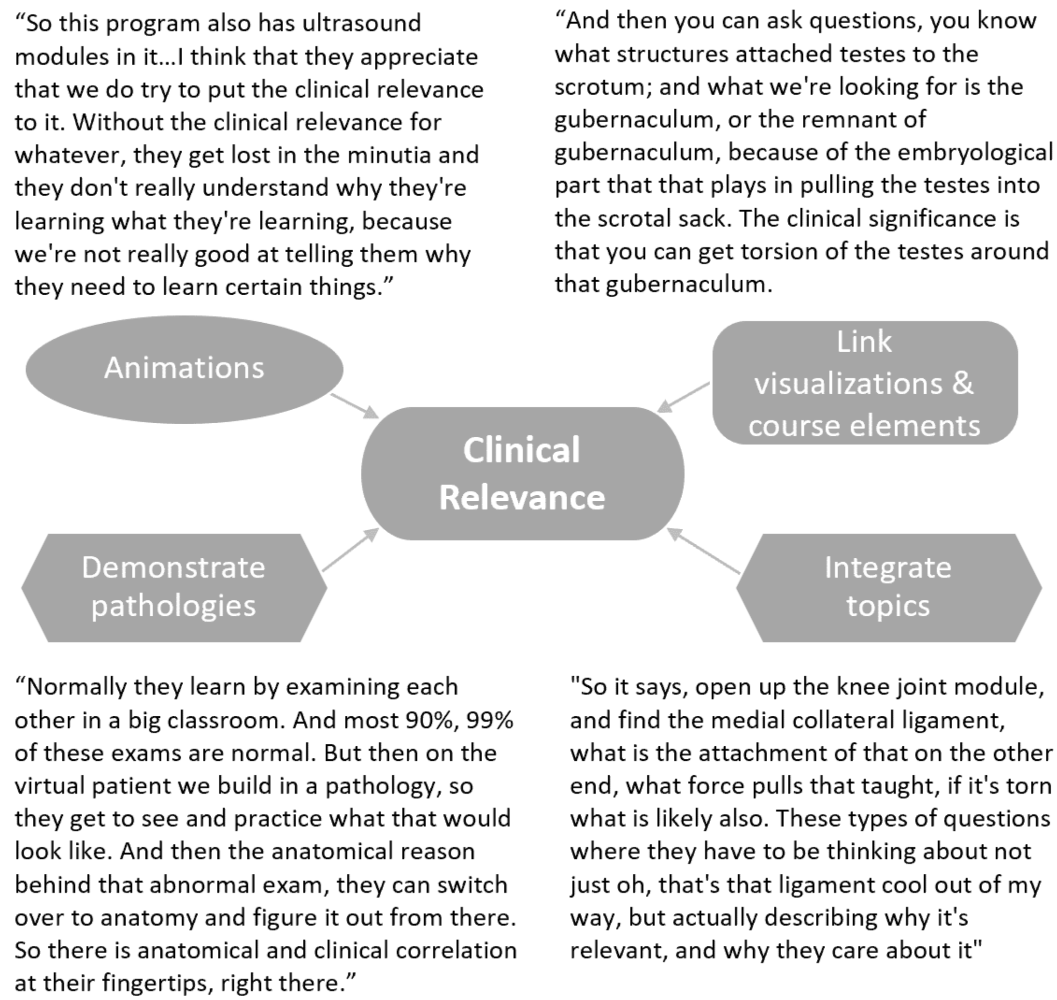



Figure 4.6: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Clinical Relevance

*Imaging Interpretation*

Medical imaging interpretation was another component of clinical knowledge and skills that many participants discussed as a purpose of their curriculum. When reflecting on skills first year medical students should acquire, one participant stated:

> Definitely the ability to use medical imaging, whether CTs, ultrasound, or whatever. I think that's the huge upside of using these technologies, that their practice will be influenced by their ability to appreciate that three-dimensionality . . . We think that that's pretty important to their long-term ability to really use medical imaging effectively.

This participant expressed feelings that teaching students to apply their anatomical knowledge to the use of medical imaging is essential for preparing them to work in health care settings. Another participant described similar expectations that students learn imaging interpretation skills:

> Cross-sectional anatomy is absolutely essential for a medical student to have before they graduate. And in my opinion, to have before they hit their third year because that's when they'll be going to the radiology suite, talking to the radiologist and trying to figure out what they're looking at on chest x-rays and cross-sections.

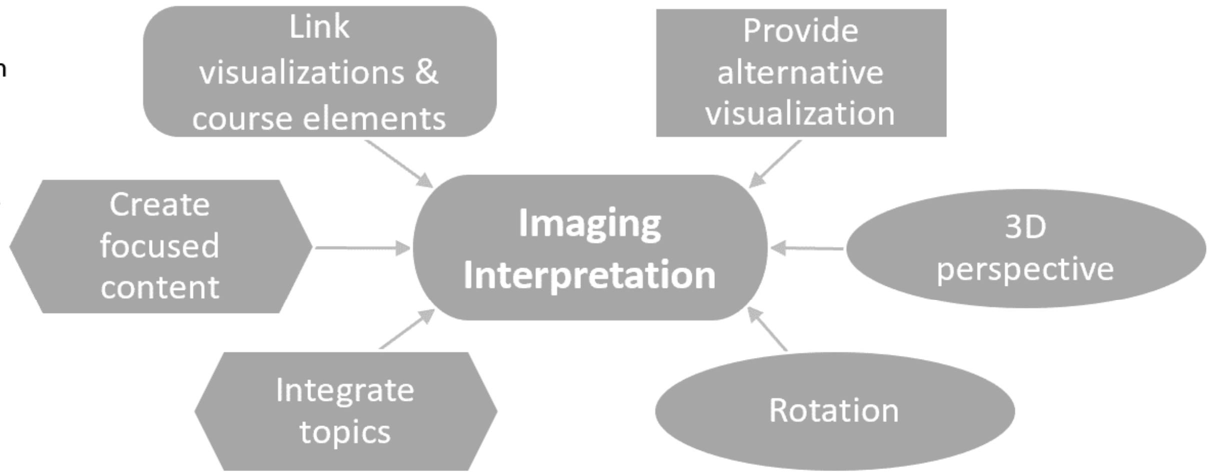
This participant feels that learning to recognize anatomy using medical imaging helps prepare students for their clinical years where they will be exposed to opportunities to apply these skills. Other participants expressed similar sentiments that the ability to accurately interpret anatomy seen in medical imaging is an important step in preparing students for clinical settings.

Participants discussed a number of ways they use 3DVT as an instructional resource for the goal of helping students build medical imaging skills. Participant quotes were used to connect subthemes of 3DVT use as an instructional resource to the purpose of imaging interpretation. Discussion by these participants demonstrates how faculty use the rotation and 3D perspective provided by 3DVT to try and help students learn to read various imaging modalities. Participants also described teaching imaging interpretation through the use of 3DVT to link visualizations and course elements, provide alternative visualization, create focused content, and integrate topics. Figure 4.7 illustrates these links, showing the ways faculty feel 3DVT can be used as an instructional resource for developing students’ imaging interpretation skills.

"The other thing that this comes with is a radiology library, which includes ultrasound images, static ultrasound images, and the nice thing here is that whenever you click on an image, it tells you where this image was taken. So here they've got this lit up to show us where on the cadaver we're looking at."

"This program allows us to teach cross-sectional anatomy in a way that the students will actually see it when they start looking at CAT scans...So the nice thing about this is you're looking at real human cadaver anatomy, but it's not CAT scan. But it correlates well with CAT scan. So I use this program pretty much exclusively when I'm trying to teach CAT scans."

"This thing you can program any way you want, you can embed drawings, you can embed CT scans, you can embed anything want into it. You can control what's on each of the screens"




"Skills, definitely the ability to use medical imaging, whether CTs, ultrasound, or whatever, I think that that's the huge upside of using these technologies, that their practice will be influenced by their ability to appreciate that three dimensionality."

"As we and other schools are moving to integrate anatomy, not just preclinical, but in those clinical years as well, it's that where that fits is pretty important... So, what we mean by that is we scan our donors. And so even from the beginning, when they're dissecting, we're encouraging them to connect the anatomy that they're putting their hands on with the CTs that they have available for those donors. We think that that's pretty important to their long-term ability to, to really use medical imaging effectively"

"I created one of those 3D reconstructions of the chest and rotated it to that particular projection and put a projection of my typical lung scan that has that defect in it. And then another one of those 3D reconstructions in the same projection next to it. So they could see very clearly where that defect corresponds to the scapula. And once they see that, then they understand that that defect is not likely to be a problem with the lung it's really more likely to be because of the scapula"

Figure 4.7: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Imaging Interpretation

*Anatomy of Procedures*

Physicians in all specialties rely on a strong anatomical understanding to perform various procedures required for patient care, and a common educational goal discussed by participants was ensuring students learn anatomy as it relates to these medical procedures. For example, one participant described using an interactive 3D table for designing lessons in an OB-GYN residency program:

> You know, this would be perfect if we would make an anatomic approach to teaching surgery and the residents. So that we actually look at a textbook of surgery, we look at the anatomy that you go through to get to your objective, and then we create a dissection model on the table that allows them to sequentially learn their surgical approach doing 3D anatomy.

This participant described how students are expected to learn the anatomy relevant to surgical procedures they perform during their residency. Similarly, another participant described the anatomical knowledge students must learn to safely perform laparoscopic procedures:

> The first lab we did was just reviewing the anatomy and then talking about trocar placement for laparoscopic procedures. Particularly, how do you miss the inferior epigastric artery and vein, and how do you place these things so that you don't hit any other major vessels when you're in there.

Like this participant, faculty who discussed teaching anatomy of surgical procedures feel that helping students better understand the relevant anatomy builds the necessary knowledge and skills for safely accessing and navigating around structures during operations.

Other faculty members discussed building student understanding of anatomy as it relates to nonsurgical procedures. One participant discussed use of 3DVT for the purpose of teaching anatomy of the heart and how it relates to clinical examination of the valves:

> The other place, I would say, is with the heart. I think that a lot of students kind of struggle with the position of valves and things like that, their orientation. And so, the ability to use the 3D like that, to do that rotation, see that orientation, I think it all makes a lot of sense, say like when it comes to hearing heart sounds.

Similarly, another participant described using 3DVT for reviewing anatomy related to areas accessed during anesthesia procedures:

> For the regional anesthesia we talk a lot about scalene blocks, and kind of that transition from scalene to clavicular spaces. So being able to trace some of the brachial plexus and the phrenic nerve, and the subclavian vasculature in that tight area has been really helpful.

Whether cardiac auscultation, scalene blocks, or similar procedures, participants discussed how they feel an important part of developing students' clinical knowledge and skills is teaching them the anatomy related to specific procedures used in patient care.

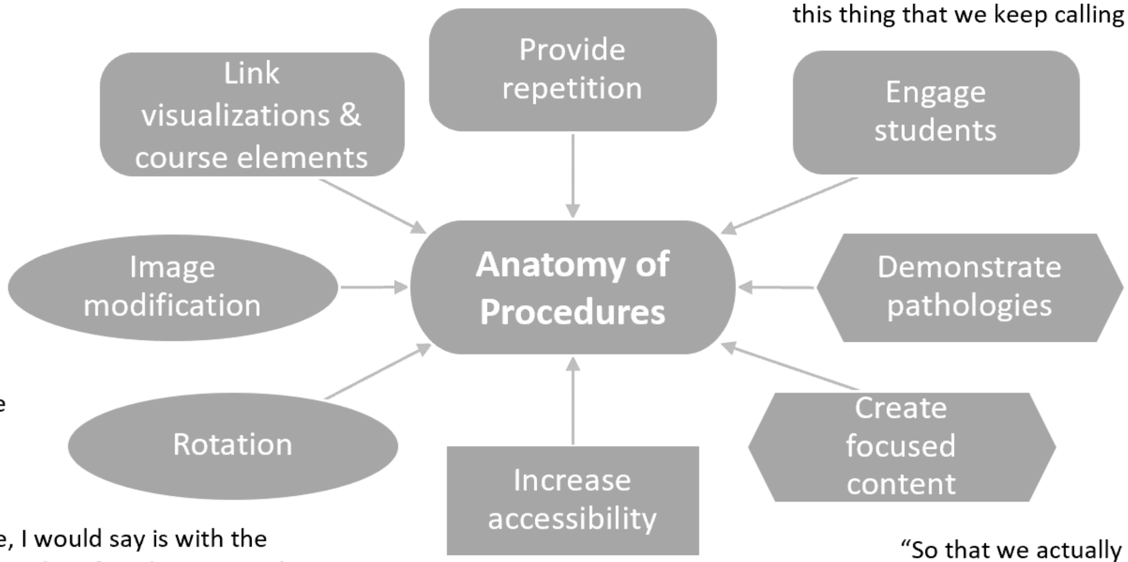
Participants talked about a wide variety of ways they use 3DVT as an instructional resource to teach students about the anatomy of procedures. Participant quotes demonstrate how faculty use the rotation and image modification provided by 3DVT for teaching anatomy of specific procedures. Participants also described how they hope to help students learn procedural anatomy through the use of 3DVT to link visualizations and course elements, provide repetition, engage students, create focused content, increase accessibility, and demonstrate pathologies. Figure 4.8 illustrates how faculty described using 3DVT as an instructional resource for teaching students anatomy as it relates to specific procedures.

"But what it does is it digitalizes the textbook. So rather than studying the anatomy textbook, while you're reading how to do the operation, you're able to actually remove the structures and do the operation while you're reading how to do it. "

"If you do a cadaver dissection, you only get to do it once…With this, you could go back and forth through the surgery up and down from inside outside as many times as you needed to, to get that same anatomic core knowledge prior to going into the operating room."

"If I teach a medical student or an intern about the Calot's triangle, or where's the cystic duct relative to the common bile duct, it's one thing for me to draw it on a chalkboard. It's another thing for me to put them into a VR simulator, and say okay, now you dissect out the structures, and you name to me, what's the cystic duct, what's the artery, what's the common bile duct, and what's the importance of this thing that we keep calling Calot's triangle?"

"Remove the skin and subcutaneous tissue and you'll see the rectus muscles. Now remove the rectus muscle and you'll see the vessels underneath, that type of thing, as we walk them through the operation."




"Understanding how we can access them, and how we can safely navigate around the structures…They can be annotated, there can be transparency involved, you can place pathology, such as tumors, brain aneurysms, so it's flexible."

"The other place, I would say is with the heart. I think that a lot of students struggle with the position of valves and things like that, their orientation. And so the ability to use the 3D like that, to do that rotation, see that orientation. I think it all makes a lot of sense, say like when it comes to hearing heart sounds."

We are so super specialized on our services, unfortunately, that not all the students are going to get exposure to an inguinal hernia repair or an appendectomy…So using alternative means whether it's 3D technology, interactive videos, we're looking for ways to provide standardization."

"So that we actually look at a textbook of surgery, we look at the anatomy that you go through to get to your objective, and then we create a dissection model on the table that allows them to sequentially learn their surgical approach doing 3D anatomy."

Figure 4.8: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Anatomy of Procedures

*Diagnosis and Disease Management*

Finally, several participants shared how teaching diagnosis and disease management is an important part of their curriculum. For example, when talking about the purpose of the surgical clerkship rotation one participant stated:

> Our primary goal is to teach surgical diseases and surgical management. It's also an introduction to be a surgeon and what that means. So, I think that those are probably the main things, you know, how are we different than internal medicine, how do we deal with problems differently, what are surgical diseases, how to communicate with surgeons, and how to recognize when somebody needs surgery.

This participant described how students in their surgical clerkship are expected to understand what diseases are encountered in the specialty, and how they can be treated surgically. Another participant described teaching disease management in the OB-GYN residency program:

> Residency, however, is all clinical, and you just depend on them to remember that core anatomy and when you go over critical topics, you kind of review the anatomy and you kind of review the physiology, but then you apply it in a clinic topic. Like ovulation; you still study the ovary and menses and fertilization and all of this, but you really then go into the medications used for ovulation induction, and what do you do when somebody's infertile.

This participant described how learners are expected to not only have the foundational knowledge, but also the clinical knowledge and skills to think about the methods and medications used for the treatment of a particular diagnosis.

Only one participant talked specifically about how they use 3DVT as an instructional resource to address diagnosis and disease management learning outcomes. This participant described using 3DVT to demonstrate pathologies and allow students to practice making diagnoses of visual pathway defects. Figure 4.9 illustrates this link between the subtheme for 3DVT use as an instructional resource and the purpose of teaching diagnosis and disease management.

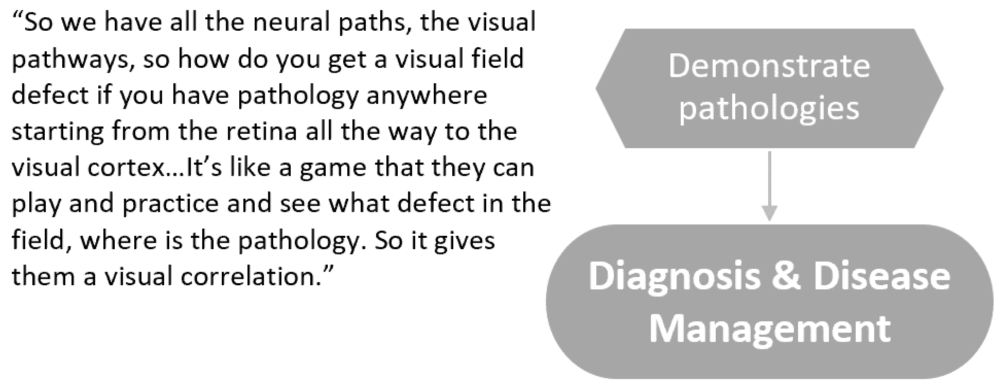



Figure 4.9: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Diagnosis and Disease Management

*Summary: Clinical Knowledge and Skills*

In summary, participants discussed educational goals in four areas related to the development of students’ clinical knowledge and skills: clinical relevance, imaging interpretation, anatomy of procedures, and diagnosis and disease management. Most participants discussed clinical relevance and described beliefs that helping students understand anatomy in a clinical context allows them to see the importance of what they are learning. Participants also discussed a desire to build students’ clinical knowledge and skills by teaching them to apply their anatomical knowledge to the interpretation of medical imaging. Additionally, faculty described how they believe students need to understand anatomy as it relates to medical procedures so that structures can be safely accessed, examined, and/or navigated around.

A few of the participants described teaching students about the diagnosis of diseases in a given field, as well as how these diseases are managed through medical and/or surgical approaches. Table 4.8 provides a summary of the subthemes related to the purpose of providing students with clinical knowledge and skills. Figures 4.6-4.9 illustrate the multitude of ways participants described how they use 3DVT for trying to achieve each of these clinical educational goals. Participants talked most about the use of 3DVT for teaching imaging interpretation and anatomy of procedures.

Table 4.8: Summary of Clinical Knowledge & Skills Subthemes

| **Clinical Knowledge & Skills** | |
|---|---|
| Clinical relevance | Helping students develop a holistic view where they can see the anatomy being learned within the context of clinical settings. |
| Imaging interpretation | Teaching students to apply their understanding of anatomy to the use of medical imaging. |
| Anatomy of procedures | Understanding anatomy as it relates to specific procedures so that structures can be safely examined, accessed, or navigated around. |
| Diagnosis & disease management | Training physicians who can think about diagnosis of diseases and management of diagnoses through medical and surgical therapies. |

**Preparing for Work as a Physician**

Work as a physician is multifaceted and requires a broad skill set. In addition to a strong foundational and clinical knowledge base, faculty described a need for students to develop personal traits and skills which will help them work more effectively throughout their careers. When discussing the purpose of education in their program, some participants described learning outcomes related to personal qualities students need for successful work as a physician. Faculty who talked about preparing students for work as a physician discussed goals related to strengthening students' a) interpersonal skills, b) self-directed learning, and c) procedural skills. Participants also described the ways they feel 3DVT use can help students develop these characteristics which allow them work effectively in health care settings.

*Interpersonal Skills*

Faculty participants described a number of interpersonal skills they hoped to instill in students to prepare them to work collaboratively with patients and other members of the health care team. For example, one participant highlighted the importance of communication skills, stating "[In] the clerkship they need to be able to talk to the patient, get the information, synthesize it." Another participant highlighted how they see leadership as an important skill for certain residency programs, stating "If it's an academic type program, certainly you want to develop the research and the leadership potential." Finally, several participants emphasized teamwork, such as a preclinical faculty member who explained:

> You have to learn how to build the team and rely on a team and this really gives them that first experience where they're really challenged with teamwork and team skills and sort of working through some of that conflict management process.

This participant described their perception of the importance of helping students develop teamwork skills since patient care requires multiple people working together. Participants like these expressed views that helping students develop interpersonal skills such as communication, leadership, and teamwork represents an important part of preparing them for successful workplace relationships.

A few participants described the ways they feel 3DVT use in the curriculum promotes development of students' interpersonal skills. These participants described trying to work on building students' communication, leadership, and teamwork skills through the use of 3DVT to engage students and deliver team training. Figure 4.10 illustrates how faculty described using 3DVT as an instructional resource in ways they felt helped students develop interpersonal skills.


Figure 4.10: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Interpersonal Skills

While several participants described using 3DVT for teaching interpersonal skills, another participant expressed feelings that the technology wasn't as successful in providing team training:

> Because we do dissections as a team process, and there's more to dissect than any one of them could do, it also provides a real great team building experience for our cohorts. And that's a unique part in anatomy, as it relates to spending that time in the lab . . . the other thing that I think a 3D projection doesn't provide is it doesn't teach our learners that sense of teamwork, which is really helpful in being a physician because in

> patient care, you also can't just do everything yourself. . . So, there's a lot of side benefits to cadaveric anatomy dissection, that doesn't happen with a 3D projection.

This participant felt that dissection experiences were better able to help students develop teamwork skills because 3DVT use didn't require students to work together.

*Self-Directed Learning*

In addition to interpersonal skills, participants also discussed their belief that students should develop the skills necessary for self-directed learning. During their career, physicians must continue learning as they stay up to date on new research, guidelines, and treatment methods. Two participants expressed sentiments that medical education should develop student interest in, and ability for, self-directed learning. One participant described promoting student-directed learning in a preclinical anatomy lab:

> I was also hoping it would be useful in sort of helping them do some self-discovery . . . And that it would give them that opportunity to in a real time say, Oh I have a question, here's my resource, you know, Dr. [X] is busy on the other side of the room, let's try and figure this out on our own and see where we can go.

This participant made 3DVT available in the lab so that students had an opportunity to direct their own learning when the instructor was busy. Another participant described how they hope using novel technologies to engage students will stimulate their interest in learning:

> Now, I don't know, you can tell me does engagement mean retention or interest or future self-learning? . . . Is it a novelty that will wear off, if that's all you teach from? Or, does it really stimulate that part of our brain that makes us want to learn more?

These participants use 3DVT to create learning opportunities that they hope will spark students' interest in future learning and allow practice of self-discovery. They feel that by preparing students to be self-directed learners they can help prepare them for work which requires life-long learning.

These two participants also described how they use 3DVT as an instructional resource for trying to develop students’ self-directed learning skills. One participant described encouraging self-directed learning through the use of 3DVT to engage students. Another participant described how the 3D perspective provided by the technology helped students use the 3DVT for self-guided learning in the lab. Figure 4.11 illustrates how faculty described using 3DVT as an instructional resource to develop students’ self-directed learning abilities.

“I was also hoping it would be useful in sort of helping them do some self discovery. There's usually a little bit of fear associated with anatomy, particularly early on, because they don't understand where this structure is in relationship to another structure. And there's some concern that I might cut something important or not.”

“If you can just come into a classroom where people are using the table compared to a classroom where you're giving a lecture, they are so much more engaged. Now, I don't know, you can tell me does engagement mean retention or interest or future self learning? …Now is it a novelty that will wear off, if that’s all you teach from? Or does it really stimulate that part of our brain that makes us want to learn more.”

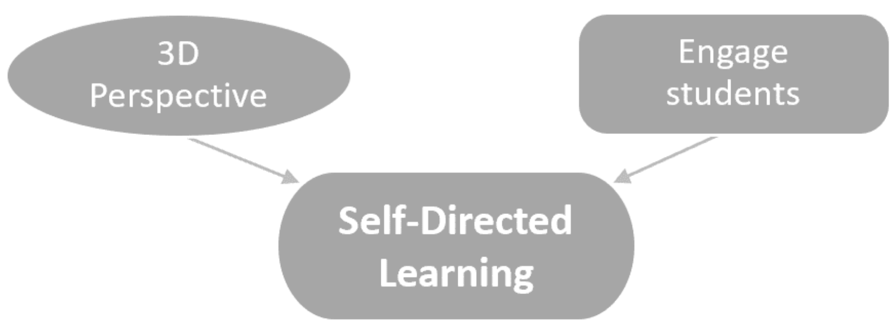



Figure 4.11: How Faculty Use 3DVT to Try to Achieve the Goal of Teaching Self-Directed Learning

*Procedural Skills*

The final way participants described fulfilling the purpose of preparing students for work as a physician was by teaching procedural skills. For example, one participant described the type of practical skills ophthalmology residents learn in simulation labs:

> The simulation, the 3D stuff also allows you to practice skills. So, the skill labs for surgical specialties, we set up wet labs where we use, say animal tissue to practice on, in our case, it would be pig eyes. But here, you give them a virtual eye to practice on, so that was another way. Then we have a virtual patient, and they get to practice eye exam skills on this virtual patient.

This participant described how 3D virtual models are used to teach surgical skills, as well as examination skills during the residency program. Similarly, when describing the purpose of education in surgical residency programs, one participant explained, “The one that everybody thinks about is the technical aspect, so how does the surgeon learn technical skills to be able to execute, to lead to some sort of therapy in a surgical manner.” This participant described technical skills, such as operating laparoscopic instruments, that residents are expected to learn in preparation for work as a surgeon. These participants consider developing student competence in the physical and practical skills of clinical care as one purpose of medical education in their programs.

Several participants described using 3DVT as an instructional resource to teach students procedural skills. These participants described trying to help students develop the technical skills needed for patient care by using 3DVT to provide repetition and create low-risk training opportunities. Figure 4.12 illustrates how faculty described using 3DVT as an instructional resource for teaching procedural skills.

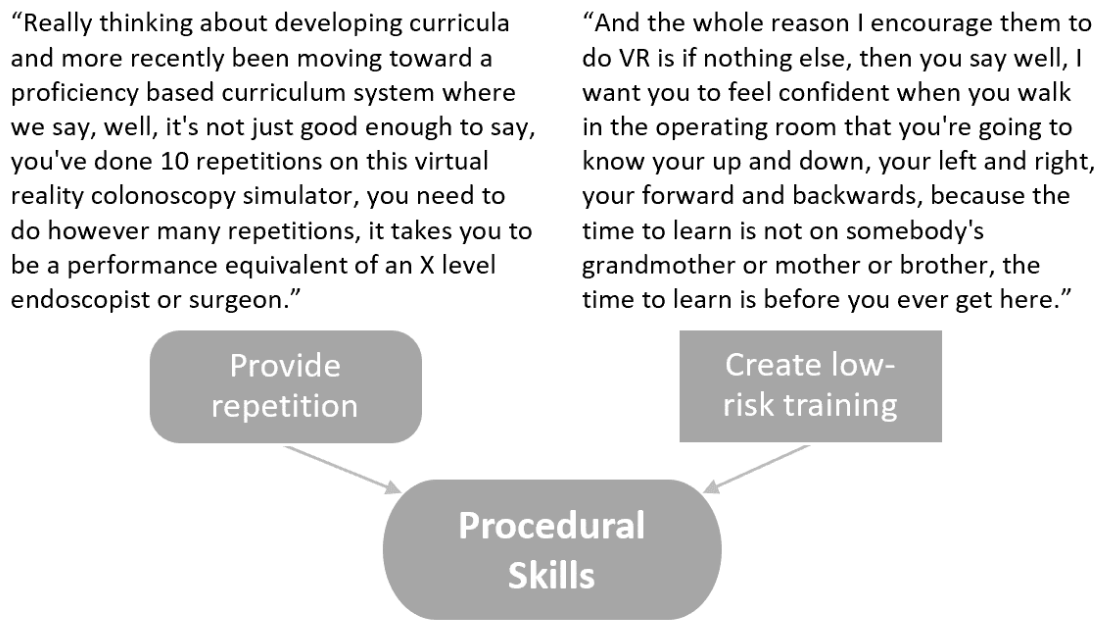



Figure 4.12: How Faculty Use 3DVT to Achieve the Goal of Teaching Procedural Skills

*Summary: Preparing for Work as a Physician*

To prepare for work as a physician, students must learn to work collaboratively in a health care team, keep their knowledge base current, and provide patient care through effective use of procedures. Participants discussed educational goals in three areas related to preparing students for work as a physician: interpersonal skills, self-directed learning, and procedural skills. Participants explained that one purpose of their curriculum is to provide students with the interpersonal skills needed to lead a team, communicate effectively, and work collaboratively. A couple of participants discussed how they work towards the goal of building students' self-directed learning skills by providing opportunities for self-discovery and inspiring interest in learning. Finally, a few of the participants described how teaching students to develop competence in the technical skills needed for patient care is one goal of their curriculum. Table 4.9 provides a summary of the subthemes related to the purpose of preparing students for work as a physician. The various ways participants described how they use 3DVT for trying to achieve these goals were shown in Figures 4.10-4.12.

Table 4.9: Summary of Preparing for Work as a Physician Subthemes

| **Preparing for Work as a Physician** | |
|---|---|
| Interpersonal skills | Teaching students to work collaboratively, communicate effectively, and understand the importance of being prepared. |
| Self-directed learning | Providing students with the interest in and ability for self-directed learning. |
| Procedural skills | Developing student competence in the physical and practical skills of clinical care. |

**Summary: Purposes**

Thematic analysis generated three major themes that describe what faculty see as the purpose of anatomy education. Subthemes further explore the knowledge, skills, and attitudes faculty hope students acquire from the curriculum. The majority of participants talked about foundational knowledge and skills students need including a) fundamental understanding of anatomy b) knowledge of form and function, and c) 3D understanding of the human structure. Faculty participants also described clinical knowledge and skills they feel students must develop to work in health care settings. These participants described clinically-oriented educational goals such as understanding the clinical relevance of anatomy, applying anatomical understanding to imaging interpretation, understanding the anatomy of specific procedures, and knowing how to think about diagnosis and disease management. Finally, participants discussed preparing students for work as physicians by strengthening students' a) interpersonal skills such as communication, leadership and teamwork, b) interest in and ability for self-directed learning, and c) procedural skills. Figure 4.13 provides a diagram illustrating the themes and subthemes which describe what faculty see as the purpose of anatomy education. To explore how faculty use 3DVT for trying to achieve these educational goals, participant quotes were used to link descriptions of 3DVT use with specific learning outcome subthemes. The links that were found between each subtheme for purpose and the subthemes for use of 3DVT as an instructional resource were shown in Figures 4.3-4.12. Overall, faculty talked about a wide variety of ways they use 3DVT as an instructional resource to try and help students obtain certain knowledge, skills, and attitudes. Faculty most commonly mentioned 3DVT use in relation to fundamental understanding, 3D understanding, imaging interpretation, and anatomy of procedures.

*Content*

The next curricular element explored in relation to faculty use of 3DVT was content. Lattuca and Stark (2011) define content as "subject matter selected to convey knowledge, skills, and attitudes" (p. 4). Faculty use of 3DVT was examined in relation to content by exploring the anatomy topics faculty discussed teaching using 3DVT. Additionally, because content and purposes of a curriculum are closely related, the knowledge, skills, and attitudes conveyed by the subject matter were also examined. In exploring this academic plan element, the themes generated from analysis were used to answer the following research sub-question:

- What content is taught using 3DVT, and what knowledge, skills, and attitudes are faculty trying to convey?

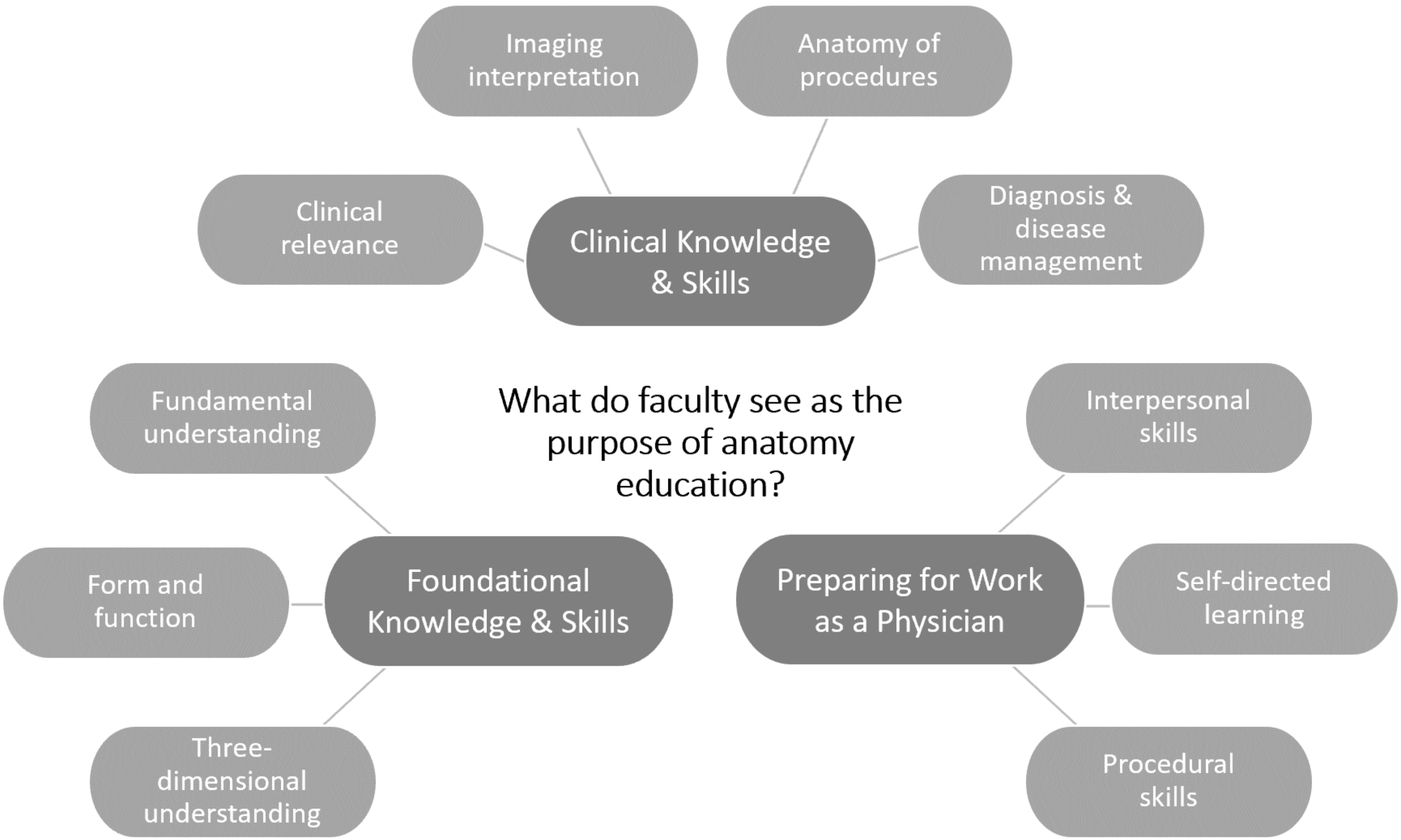



Figure 4.13: Themes and Subthemes of 3DVT Use Related to Purposes

Thematic analysis resulted in thirteen subthemes representing distinct topics faculty described teaching using 3DVT. These subthemes were grouped into three major themes describing how faculty use 3DVT for teaching: 1) Systemic Anatomy, 2) Regional Anatomy, and 3) Clinical Anatomy. The following sections discuss each of the three themes and related subthemes, including how the subject matter of each subtheme is related to purposes. A final section summarizes the themes related to content taught using 3DVT.

**Systemic Anatomy**

Faculty discussed using 3DVT to teach content related to the different organ systems of the human body. Systemic anatomy content includes subject matter detailing the individual organs or elements of each discrete functional system of the body. Participants described using 3DVT to teach content related to the following systems: a) cardiovascular, b) nervous, c) muscular, d) skeletal, and e) respiratory. This section will describe the systemic anatomy content faculty teach using 3DVT, and describe the knowledge, attitudes, and skills faculty are trying to convey by covering these topics.

*Cardiovascular*

Many of the faculty participants described using 3DVT to teach content covering the heart and blood vessels of the cardiovascular system. For example, one participant described teaching blood vessels using interactive 3D tables in the lab:

> You can see how this sort of builds itself up, because what we're doing then is we add the arteries, the posterior trunk of the internal iliac, you know, all those kinds of things into it. And then testicular veins, and we

> talk about how, just like the ovarian veins, they empty into the inferior vena cava and the left renal vein.

This participant teaches fundamental knowledge by using the 3D table to demonstrate pathways of various blood vessels. Another participant described teaching procedural anatomy related to heart auscultation by using 3D displays to demonstrate the orientation of heart valves.

In addition to teaching students fundamentals of the blood vessels, one participant described using 3D displays of blood vessels for the goal of helping students develop 3D understanding and imaging interpretation skills:

> I did ultrasound so I sort of got the idea of what to do, so we work on the level [of organs] . . . And the pancreas, how you get all of the pancreas by using your superior mesenteric vessels as a guide and then you work towards it. The portal vein, that's also an amazing structure. That's neat, because it's not placed in such a position where you could see it sagittally, it's not that way at all, its inclined to one side . . . They ask how do we observe the portal vein. So, I will say it's a right oblique position then you can get it. Because of my scanning techniques, I could understand that position of the portal vein, and relationship to the body.

This participant uses the portal vein as an example to help students see how the 3D orientation of structures is related to viewing them using imaging. Similarly, this participant also described teaching the clinical relevance of blood vessel form by using the 3D display to discuss potential pathways of aortic thromboses.

*Nervous*

Similar to the cardiovascular system, faculty participants also described using 3DVT to teach content covering the structures, pathways, and innervation of the nervous system. One participant described using an interactive table to teach fundamental understanding of the nervous system:

> I can control this sort of thing, now unfortunately these buttons don't work in anything other than the table, but it tells the students what they have to look at and what they have to know about . . . you can add the nervous system innervation and talk about the parasympathetic and sympathetic control of this particular part.

Participants like this described using 3D visualizations to teach fundamental anatomy of the nervous system by demonstrating the pathways and innervations of nerves. One participant not only covered the pathways of nerves, but also included discussions of neural lesions to teach students about the clinical relevance of particular nerves.

Participants also described teaching structures of the nervous system using 3DVT and explained how, in their view, this adds to students' 3D understanding. For example, one participant described using 3D visualizations to demonstrate the relationship of nerve pathways:

> There's the option called original nerve path . . . and I could select the genitofemoral nerve and say show me the origin path. And basically, what it would do, it would make the whole body transparent and I could trace it up to where it was the whole nerve. And then it showed the bifurcation, how the genital branch is in the spermatic cord and the femoral is a little bit more lateral. And you just go, oh, well that's so simple to visualize now.

This participant explains how visualizations of nerve branches can be used to show students the relationships and relative orientations of structures. Another participant described using 3DVT for teaching neurosurgical residents about the 3D relationships of the nervous system, and to discuss the procedural anatomy related to safely accessing and/or navigating around these structures during surgeries.

*Musculature*

Many of the faculty participants described using 3DVT to teach content covering structures of the muscular system. One participant described using 3D interactive tables to teach fundamentals of the muscular system during lab, stating, “then we started adding the lateral wall muscles and ligaments, and this done in a stepwise manner. And then what I asked them to do was identify the piriformis muscle, the obturator internus, the sacrotuberous ligament.” While this participant focused on general structure identification, another participant described using 3D visualizations to teach students about procedural anatomy:

> We're using the [3D] tables to create an operative approach to learning, meaning we're taking the 3D anatomic module, taking a textbook approach to what the operation would be that we're interested in teaching our learners and then we're dissecting the three dimensional structures out of that focusing on muscles, nerves, lymphatics and vessels.

By creating visualizations demonstrating muscles of a particular operation, this participant wants residents to review anatomical knowledge as it relates to surgical procedures.

In addition to teaching students about fundamental and procedural anatomy, participants also described teaching students about form and function and 3D relationships by covering structures of the muscular system using 3DVT. For example, one participant described using 3DVT to help students understand the layout of muscles in the shoulder, explaining that “understanding serratus anterior is tricky. You know, why when you pull the scapulae away in the back don't you see the subscapularis. Looking at the 3D will help them to understand why that is.” By using 3D visualizations to show the relationships of complexly oriented muscles, this participant tries to build the students' 3D understanding of anatomy. Similarly, another participant described using virtual 3D models to show students how muscle orientation in the orbit is related to ocular motility, hoping to build their ability to connect form and function.

*Skeletal*

Osteology was another topic that faculty described teaching using 3DVT. Faculty described teaching fundamental anatomy of the skeletal system by using 3DVT to teach students about the bones of the body and their individual features. For example, one participant described using 3DVT to teach topics that involve complex 3D anatomy such as the vertebrae, explaining, "the vertebrae have an awful lot of anatomy stuffed into a very small area. And so those are the ones that I focus on." Another participant described replacing a traditional lecture for the ophthalmology residents with a hands-on session that included osteology:

> We converted it into a hands on experience that will take the difficult elements, for example, the bones of the orbit, you will take it and instead of just saying these are the bones that make the roof, the floor, the medial wall and the lateral wall, you actually color [them], they get to dissect them apart, they can rotate them and study them, and what are the different foramina within it? And what are the different fissures within it? What structures pass through?

This participant hopes to build students' fundamental understanding of the orbit by using the 3D models to cover the relevant bones and their features. Other participants also described using 3D models to teach anatomy of the skull, specifically areas involving complex bony anatomy, such as the inner ear.

*Respiratory*

A couple of participants described using 3DVT to teach content covering structures of the respiratory system. For example, one participant described using 3D visualizations for teaching pulmonary fellows about the bronchial tree:

> They're used to just seeing an endoscope through the trachea, so they’re only used to seeing from the inside, never from the outside . . . Even when they were first- and second-year students, and I'm sure through residency, they never got to follow into the segmental bronchi. They never got to see that distribution, they've only looked at it on netter images or something. But being able to rotate, and I can make each lobe kind of transparent, so they can see the distribution a little bit clearer.

This participant described using 3D visualizations because they felt it helped pulmonary fellows better appreciate the 3D structure of the bronchial tree segments viewed during endoscopic examination. Similarly, another participant described using 3D reconstructions to help residents understand how the orientation of lungs relative to surrounding structures affects how nuclear imaging scans should be interpreted. These participants use 3DVT to help students learn to apply 3D understanding of anatomy to procedures and imaging interpretation involving the respiratory system.

*Summary: Systemic Anatomy*

Overall, faculty discussed using 3DVT to teach a wide range of topics related to the different organ systems of the human body. Faculty participants described using 3DVT to teach a) the structures and pathways of the cardiovascular system, b) the pathways and innervations of the nervous system, c) the locations and functions of muscles, d) the organization and features of the skeletal system, and e) the orientation and distribution of respiratory system structures. Table 4.10 summarizes the subthemes of systemic anatomy content, including the knowledge and skills faculty hoped to convey by covering content in these areas.

Table 4.10: Summary of Systemic Anatomy Subthemes

| Systemic Anatomy | |
|---|---|
| Cardiovascular | Subject matter related to heart and blood vessels is taught to try and help students achieve a wide range of learning outcomes, from foundational knowledge, to clinical knowledge and skills including clinical relevance, imaging, and procedural anatomy. |
| Nervous | Content related to the nervous system is taught by faculty who hope to encourage development of students' fundamental and three-dimensional understanding, as well as their understanding of procedural anatomy and clinical relevance. |
| Muscular | Teaching students about muscles is used to convey information related to foundational knowledge and skills, as well as anatomy of procedures and clinical relevance. |
| Skeletal | Visualizations are used to teach students about the fundamental anatomy related to bones of the body and their individual features. |
| Respiratory | Content is used to try and help students gain a 3D understanding of the respiratory system related to examination procedures and imaging interpretation. |

**Regional Anatomy**

In addition to systems of the body, faculty also discussed using 3DVT to teach content related to regions of the human body. Regional anatomy content includes subject matter detailing all of the various organs and structures found in each discrete area of the body. Participants described using 3DVT to teach content related to the following regions: a) pelvis, b) trunk, c) head and neck, and d) extremities. This section will describe the regional anatomy content faculty teach using 3DVT, and describe the knowledge, attitudes, and skills faculty hoped to convey by covering these topics.

*Pelvis*

The pelvis was one region that many of the participants described using 3DVT to teach. One participant described how they use 3D models in a preclinical lab session covering anatomy of the pelvis:

> If I want to particularly show something, I can rotate, show a side view of the pelvis, taking things away, so that they can actually see what we're looking at. And then I can ask them to identify the rectovesicular folds and the male pelvic peritoneum.

This participant, and others, described teaching students about fundamental anatomy of the pelvis by using 3D visualizations to demonstrate relevant structures from different angles. In addition to wanting to help students gain fundamental understanding, participants also described using 3DVT to try and help students develop a 3D understanding of pelvic anatomy. One participant described deciding to use 3DVT to teach preclinical students anatomy of the pelvis, explaining, “Many of the students really struggle on the pelvic area, because it's sort of a three-dimensional space area . . . and then the students really appreciated how easily it made them understand those three-dimensional relationships within the pelvis.” A number of participants, like this one, described using 3DVT for teaching students anatomy of the pelvis with the hopes that it would help them develop 3D understanding of a complicated area.

*Trunk*

The trunk, including structures of the thorax and abdomen, was another region participants described using 3DVT to teach. For example, one participant described using stereoscopic 3D models to lead demonstrations covering anatomy of the trunk:

> It was mostly on the abdomen and thorax . . . So, we work on the level, we work on the structures inside the liver, sagittal as well as cross sections, and observe small little minute details like the caudate lobe, which is very peculiar in its position . . . the big blood vessels, the superior mesenteric arteries, celiac trunk, and the veins the inferior vena cava, portal veins. Kidneys, ureters, pelvis of the ureters, trace the ureters down to the pelvis.

This participant described reviewing different structures of the abdomen, while discussing with students how their location and orientation is related to finding and viewing these structures using medical imaging. Another participant described using a 3D application to teach fundamental anatomy by using it to review structures of the abdominal wall and inguinal region for a fourth-year musculoskeletal elective.

*Head and Neck*

The head and neck region was another area participants described teaching using 3DVT. One faculty member described using a 3D application during anatomy review sessions for residents, including one session which was “an ear, nose, and throat [session] for otolaryngologists, kind of a neck review, with all the neck deep spaces and things like that.” This participant also described creating sessions reviewing neck anatomy for anesthesiology residents to provide them with information about the procedural anatomy related to scalene blocks. Other participants described using 3DVT to teach conceptually difficult areas of the head and neck, such as the orbit or inner ear. One participant explained, “I only use 3D reconstructions of complex three-dimensional things, the inner ear is actually a good example.” These participants described using 3D visualizations for trying help students develop 3D understanding of specific regions in the head and neck that have complex anatomy.

*Extremities*

Finally, a few of the participants described using 3DVT to teach regional anatomy of the extremities. These participants described teaching anatomy related to the upper and lower limbs including muscles and their movements, arterial pathways, joints, and nerves. For example, one participant described using a 3D application for teaching upper limb anatomy in a preclinical course:

> But you can also, say remove the biceps, or make it faint looking, and then you can add vessels and nerves and you can sort of make it as simple or as complicated as you want to . . . so I think that the extremities is really helpful for the students. And like I said it's also reinforced when they look at the bones and have to be able to figure out what's attaching where, you know, it all starts to make sense.

This participant described how 3D visualizations with varying levels of complexity are used in combination with other resources, such as bones, to help students study fundamental anatomy of the upper limb. Another participant described using self-directed learning modules to demonstrate the anatomy of the knee and its clinical relevance. This participant used a 3D virtual reality display to lead students in studying the fundamental structures of the knee, such as the ligaments, and asked students to consider the role of these structures in common injuries of the knee.

*Summary: Regional Anatomy*

Overall, faculty discussed using 3DVT to teach a wide range of topics related to the different regions of the human body. Faculty participants described using 3DVT to teach regional anatomy such as 3D relationships of the pelvis, imaging interpretation of the trunk, procedural anatomy of the head and neck, and clinical relevance of joint injuries of the extremities. Table 4.11 summarizes the subthemes of regional anatomy content, including the knowledge and skills faculty hoped to convey by covering content in these areas.

Table 4.11: Summary of Regional Anatomy Subthemes

| Regional Anatomy | |
|---|---|
| Pelvis | 3DVT was used to teach fundamental anatomy of the pelvis, and for encouraging development of students' three-dimensional understanding of the pelvis. |
| Trunk | 3D visualizations of the trunk were used to teach fundamental anatomy and discuss topics related to imaging of the thorax and abdomen. |
| Head and neck | 3D reconstructions are used for teaching foundational components in the complex three-dimensional areas of the head and neck. |
| Extremities | 3D is used for teaching students about basic structures of the upper and lower extremities, and their clinical relevance. |

**Clinical Anatomy**

In addition to systemic and regional anatomy, faculty also discussed using 3DVT to teach content related to clinical anatomy. Participants who described teaching clinical anatomy content discussed using 3DVT to teach topics that required students to think about anatomy in the context of clinical applications. Participants described using 3DVT to teach content related to the following clinical topics: a) procedural approaches, b) imaging, and c) pathology. This section will describe the clinical anatomy content that faculty teach using 3DVT, and describe the knowledge, attitudes, and skills faculty hoped to convey by covering these topics.

*Procedural Approaches*

One area of clinical anatomy participants described using 3DVT to teach was content related to procedural approaches. These participants described teaching students about procedures used in patient care by covering topics such as the steps involved, the anatomy encountered, and how instruments are used properly. For example, one participant described creating 3D teaching modules to cover common procedures encountered by OB-GYN residents:

> We have our episiotomy model, we're going to create a C-section model, we just did our pelvic anatomy model, and what we're going to do is create the laparoscopic model, just the approach to placing the laparoscope. And then the key one would be if we can create a hysterectomy model that allows them to get in and get out and learn that anatomy on the table prior to getting into the operating room.

This participant described using 3D models to teach students about the surgical procedures they learn to perform during their residency with the hope that they will gain a better understanding of the anatomy related to each procedure. Similarly, another participant described the initial thought process of implementing 3D simulators for surgical education:

> The Unity engine really improved in terms of making three-dimensional graphics, it then started to morph into, okay, we can teach the basic skills, but can we also start to teach some clinically relevant procedural skills? So how should a surgical resident or medical student think about approaching the dissection of the gall bladder? So how can we teach anatomy this way, too?

This participant described using simulations to teach content related to surgical procedures in a way that can help students develop their procedural skills and understanding of anatomy related to specific surgeries.

While some participants talked about using 3DVT to teach students about various operative procedures, other participants described teaching subject matter related to examination procedures. For example, one participant described teaching preclinical students about imaging procedures, stating, “I'll give them a lecture on coronary angiography, show them how they’re obtained, show them the anatomy on the coronary angiography, show them the stenosis of the coronary artery.” This participant described using a 3D video to demonstrate the anatomy related to the cardiac catheterization procedure as well as the anatomy of the coronary vessels examined using the angiogram procedure. Similarly, another participant described using virtual models to help students relate anatomy of the eye to procedures used during physical examinations:

> We go to the simulation center, we have different stations, one place they get to do the normal exam, like a bedside exam. Next one, they get to see the anatomy, the next one, they get to see the virtual anatomy I'm talking about, they get to actually interact with it. Then the third station they go, they get to practice on the virtual patient, which is all the abnormal ones.

This participant goes beyond teaching how eye exams are done by having students interact with the anatomy being examined during the procedures.

*Imaging*

Another area of clinical anatomy participants described using 3DVT to teach was content related to medical imaging. For example, one participant described content taught in a 3D virtual anatomy lab:

> We use the virtual lab mostly to teach our students cross-sectional anatomy, CT scans, MRs, ultrasound, etc. We've implemented an ultrasound education in the first-year curriculum here . . . I didn't teach

> how to acquire the image I just taught how to read the images once they were obtained.

This participant explained how 3D labs were used to introduce students to different imaging modalities and guide them in learning to interpret the anatomy seen in cross-sectional images. Another participant also described teaching imaging using 3D tools:

> Since we only have one male and female pelvis, I look at it as teaching normal anatomy. And then pulling in the CTs and MRIs to teach abnormal anatomy by comparing it to the cross-sectional stuff along the side.

This participant described using 3D models as a comparison tool for trying to help students begin to recognize abnormal anatomy seen in medical imaging. By teaching students about CT, MRI, and ultrasound, these participants give students an opportunity to practice applying their anatomical knowledge to the interpretation medical images.

*Pathology*

The final area of clinical anatomy participants described using 3DVT to teach was content related to pathology. These participants described teaching students about various disorders of structure and function that are commonly encountered in clinical settings. One participant described using 3D models created from imaging scans of patients with different pathologies:

> But when I have the ability to use actual CT scans, and I know the pathology that we're trying to show, it's easier that way. This is supposed to be an MR of an aneurism on the Circle of Willis.

This participant described helping students see the clinical relevance of anatomy by showing them pathologies related to the structures they learn about. Another participant described using 3D model case studies to get students thinking about diagnosis of diseases:

> In this particular case this cadaver only has one testis, he's missing his right testis. So, why is he missing his right testis? And the differential on that is obviously tumor, cryptorchidism, or torsion of the testis. And I asked them to try to differentiate based on the anatomical basis why. What led to the removal of his testis?

Participants like these, who discussed teaching pathology content, use 3DVT to teach students about common disorders to encourage students to develop an understanding of how anatomy is related to clinical diseases.

*Summary: Clinical Anatomy*

Overall, faculty discussed using 3DVT to teach a number of different topics related to clinical anatomy. Faculty participants described using 3DVT to help students think about anatomy in the context of clinical applications such as procedural approaches, imaging interpretation, and pathology. Table 4.12 summarizes the subthemes of clinical anatomy content, including the knowledge and skills faculty hoped to convey by covering content in these areas.

Table 4.12: Summary of Clinical Anatomy Subthemes

| **Clinical Anatomy** | |
|---|---|
| Procedural approaches | By covering topics related to procedural approaches instructors want to encourage development of students' knowledge about anatomy of procedures and competence in procedural skills. |
| Imaging | Faculty use 3DVT to teach students about CTs, MRIs, and ultrasound develops with the hope it will aid in their ability to use medical imaging effectively. |
| Pathology | Specific examples of pathology are introduced with the hope it will help students develop an understanding of how anatomical structures relate to disease, so they can see the clinical relevance and think about disease diagnosis and management. |

**Summary: Content**

Thematic analysis generated three major themes that describe what content faculty teach using 3DVT. Subthemes further explore the specific topics and subject matter faculty described teaching. The majority of participants talked about teaching systemic anatomy, including topics detailing the individual organs and elements of the cardiovascular, nervous, muscular, skeletal, and respiratory systems. Participants also described teaching regional anatomy of the pelvis, trunk, head and neck, and extremities. Finally, participants discussed using 3DVT to teach clinical anatomy content, with topics covering procedural approaches, imaging, and pathology. Figure 4.14 provides a diagram illustrating the themes and subthemes which describe the content faculty teach with 3DVT.

The content faculty taught was selected to convey different knowledge, skills, and attitudes. The systemic and regional anatomy content taught by faculty was selected to convey a number of foundational and clinical knowledge and skills, with many participants emphasizing fundamental understanding, 3D understanding, clinical relevance, and anatomy of procedures. Faculty also described how topics related to clinical anatomy were chosen to convey clinical knowledge and skills, such as imaging interpretation, anatomy of procedures, and diagnosis of disease. Clinical anatomy content related to procedural approaches was also used to develop students' procedural skills.

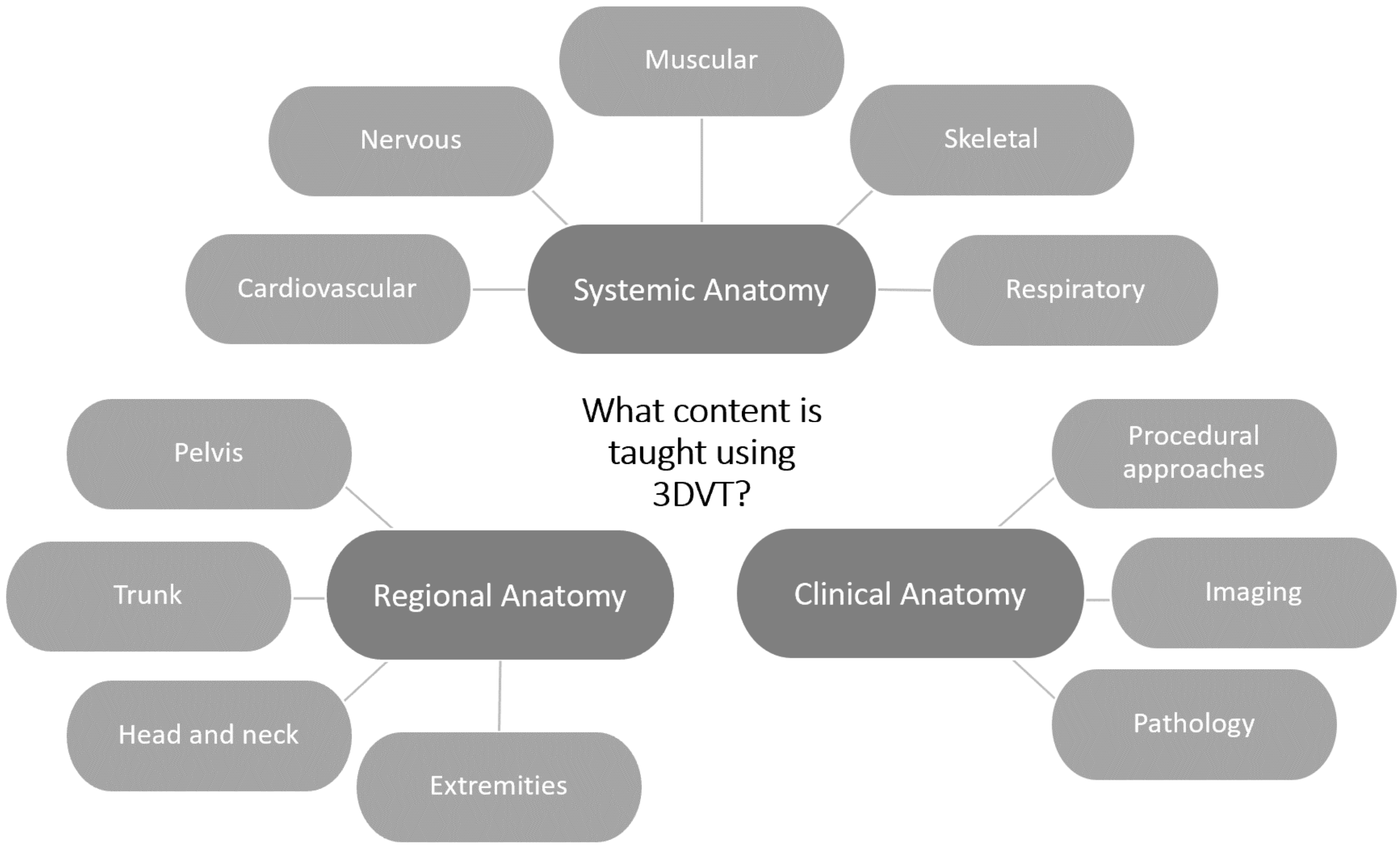



Figure 4.14: Themes and Subthemes of 3DVT Use Related to Content

*Sequence*

Sequence was another curricular element explored in relation to faculty use of 3DVT. Lattuca and Stark (2011) define sequence as "an arrangement of the subject matter and experiences intended to lead to specific outcomes for learners" (p. 4). How an instructor designs the sequence of subject matter and experiences in a curriculum is important because it reflects their beliefs about how knowledge is best transferred. Faculty use of 3DVT was examined in relation to sequence by exploring when faculty use 3DVT in the curriculum and how they arrange the content presented. In exploring this academic plan element, themes generated from analysis were used to answer the following research sub-questions:

- How do faculty arrange the subject matter and learning experiences associated with 3DVT use? How is sequence used to try to achieve desired learning outcomes?

Thematic analysis resulted in six subthemes representing the sequence of content and 3DVT use described by faculty participants. These subthemes were grouped into two major themes addressing how faculty describe: 1) Arrangement of Subject Matter, and 2) Arrangement of Learning Experiences. The following sections discuss these themes and related subthemes, including how faculty described using different arrangements for trying to achieve desired learning outcomes. A final section summarizes the themes related to how faculty sequence the use of 3DVT.

### Arrangement of Subject Matter

Instructors often organize the content they present in a particular way, and participants described several ways they arrange the subject matter taught using 3DVT. The subthemes related to subject matter arrangement represent the different organizational schemes faculty use to sequence the material taught using 3DVT. Faculty described arranging content according to three organizational schemes: a) anatomical, b) procedural, and c) progressive learning. This section describes how faculty arrange content according to these schemes and participant perceptions of how these arrangements are used to achieve desired learning outcomes.

#### *Anatomical*

Anatomy is frequently divided into body systems or regions, and participants described organizing the content taught using 3DVT based on these common anatomical classifications. One participant described designing a preclinical anatomy course that included the use of 3D virtual dissection tables, stating, “I then had to work it into our single pass organ-based system curriculum. And what the tables allow me to do is modify things so I can focus in on an organ system of the week.” This participant described organizing the content taught in the course according to the different body systems studied in the curriculum. Similarly, other participants described arranging content according to regions of the body relevant to the curriculum, such as a pelvis review module one participant made for OB-GYN residents. These participants arrange content based on common anatomical divisions with the hope that it will help students build their foundational understanding of the organization and function of body structures.

*Procedural*

While some participants described organizing content anatomically, others described arranging subject matter based on certain procedures. One participant described thinking about the organization of content in a residency program, stating "There's some standard procedures that they always do, so how do you teach the anatomy of those procedures and what to look out for." This participant feels they can help residents prepare for what to expect during procedures by designing 3D interactive lessons around the anatomy they will encounter. Another participant explained their view of the importance of helping students see anatomy in the context of surgical procedures, saying, "rather than just rote anatomy, I learned these muscles and these blood vessels and this, we allow them to see how it's applied to certain core operations like C section or hysterectomy." By arranging content based on procedures, participants help students to study structures in the context of thinking about how to safely access and navigate around them.

*Progressive Learning*

Some of the faculty participants described presenting subject matter in an order of increasing complexity to allow for progressive learning. These participants described using 3DVT to cover simple topics early on, and then to cover increasingly complicated subjects as students progressed through the program. One participant described the organization of content taught in an OB-GYN residency program:

> There's always progressive learning in residency. And while an intern may learn how to do a vaginal delivery and an episiotomy repair, the fourth year is going to be learning how to do vaginal hysterectomies. So, as we develop more and more of these [3D learning sessions], they will be done with the thought of progressive learning.

In this case the content taught using 3D interactive tables is arranged not only according to specific procedures, but the procedures are taught in order of increasing complexity.

Another participant described a similar organization of increasingly complex content in a nuclear medicine program:

> So, your first step in understanding imaging is to know the normal structure, and the normal deposition of the various tracers that we use in nuclear medicine. Once you understand the normal distribution of the tracer, then you can start understanding the abnormal distribution of the tracer.

This participant explains how residents must first understand what imaging should look like normally, before moving on to learn about abnormal appearances. Similarly, other participants described how surgical residents study normal anatomy and basic procedural steps before working up to procedures involving more complex pathologies. This progressive arrangement of content is used by faculty who hope to help students build knowledge and skills incrementally as they move through the curriculum.

*Summary: Arrangement of Subject Matter*

In summary, faculty discussed several different ways they arrange the subject matter taught using 3DVT. Faculty participants described arranging content based on a) anatomical divisions to provide students with fundamental information, b) procedural steps to allow students to learn structures in the context of certain clinical practices, and c) progressive learning to help guide incremental development of knowledge and skills.

Table 4.13 summarizes the subthemes related to how faculty arrange subject matter taught with 3DVT.

Table 4.13: Summary of Arrangement of Subject Matter Subthemes

| Arrangement of Subject Matter | |
|---|---|
| Anatomical | Subject matter is organized into a systems-based approach where individual organ systems are taught in a given period or a regional approach where different areas are focused on. |
| Procedural | Faculty arrange content based on specific procedures students are expected to learn. |
| Progressive learning | Faculty arrange subject matter so that simple topics are covered first, followed by increasingly complicated topics. |

**Arrangement of Learning Experiences**

Instructors must decide how to sequence the interactions with students in a curriculum, and participants described several ways they arrange the learning experiences associated with 3DVT use. The subthemes related to the arrangement of learning experiences represent when in the curriculum faculty use 3DVT, for example early on to introduce students to topics, or later after students have already had some involvement with the material. Participants described arranging learning experiences to allow for: a) early use of 3DVT, b) later use of 3DVT, and c) spread out use of 3DVT. This section describes how participants arrange 3DVT learning experiences and how they feel these arrangements help to achieve desired learning outcomes.

*Early Use of 3DVT*

Many of the participants described using 3DVT early in the learning process. These participants described implementing learning experiences involving 3DVT use when students first start learning about new topics, before other types of interactions. For example, one participant described how a colleague created learning materials for students to use prior to lab sessions:

> He's implemented little screenshots that are relevant to that lay-out. So, if they want to look at the anatomy of that region ahead of time, not just from the books, but also they can see it in 3D and know what to expect.

This participant, and others, described using 3DVT early on to introduce students to material in preparation for subsequent learning experiences such as lab dissection. Another participant explained their decision to use 3DVT for the early stages of student learning:

> I think that it's got to be early. I think our experience is if we hold off and use it as review, they're less likely to use it as part of their learning. So, we use it pretty early on. For example, when I introduce a topic, [like the] broad ligament, I'll show static pictures of a couple of different views and then I'll go right in and use the 3D to help them see that more dynamically. So, I use it right off the bat.

This participant described using 3DVT to introduce topics because they believe earlier use of 3DVT will lead to increased adoption of the technology. These participants, who described early use of 3DVT, felt it would allow students to preview material prior to other sessions and increase adoption of the technology.

*Later Use of 3DVT*

While some participants described using 3DVT early in the learning process, others described later use of 3DVT. These participants described implementing learning experiences involving 3DVT use after students had already been introduced to topics through other types of interactions. One participant described using slides with static 2D images before introducing 3D models:

> I always want to do slides first to talk about the tissues in general, put some names to them, why do we care about them, why are they relevant, so we can even just talk about concepts and then we'll look at the visualization. Because then they go, oh that's why I care about that, that's why that's interesting, that's why that's on top of that, and that's why I need to be aware of this, you know, those types of things. Where if I just started showing it, I think they're kind of like, what's that thing again? I don't know what that is yet. I want to build a foundation before we go into the actual 3D.

This participant provides context and relevance to content learned using 3DVT by first using lecture slides to build students' base understanding. Similarly, another participant described having students build a foundational understanding by reading an iBook prior to the 3D lab sessions. He felt this allowed for deeper learning during the lab session because students were prepared to interact with the models, answer questions, and discuss concepts with peers.

Participants also described how later use of 3DVT allowed students to practice the application of their understanding. One participant described the use of virtual labs after students had already done dissection labs:

> Most of the time, we use the virtual anatomy lab to teach radiographs, and those are introduced after they've already had the anatomy taught to them in the cadaver lab. So, it's used more as a review of what they already know. And then once they know the basic anatomy, then we'll go to virtual lab and teach them the cross-sections.

This participant explains how the 3D lab helps students practice applying their anatomical knowledge to imaging interpretation. Similarly, another participant describes how meaningful application may not occur if a base of understanding is not developed prior to VR simulator use:

> I do think it's important to teach the students, whether a didactic session or any sort of that flipped learning environment, sort of the basics behind

> what's underlying whatever VR simulation you want to do. And so, the way we ended up doing that was that we would actually have people go through the online didactic modules to really learn the principles of endoscopy before they ever started their technical skills training on the simulator. And that was really important because we were watching some of the residents skip the didactic and say, well, I'll save that to the end . . . And it really impaired their ability to think meaningfully about why they were engaging in certain motions in the process of a colonoscopy.

This participant wants students to learn about the procedures first, so that the time spent using the VR simulator can focus on applying that foundational knowledge to the development of technical skills.

*Spread Out Use of 3DVT*

While some participants described using 3DVT earlier or later in the learning process, a few described spreading out the use of 3DVT. These participants described implementing learning experiences involving 3DVT throughout students' learning process, interspersing 3DVT use among other types of interactions. One participant described how VR simulators are used throughout the ophthalmology residency program:

> Throughout the residency. Like I said, the morning educational sessions, they use it. And then we have other simulators too, from other companies other than the ones that I made. There is one for direct ophthalmoscopy, indirect ophthalmoscopy, one for cataract surgery, those are incorporated into their curriculum. They get dedicated time to go and practice on those at a time that's appropriate to their level of training.

This participant describes how a variety of simulations are available to residents throughout their training to accommodate learners at different levels. Another participant described how students have access to their 3D application throughout the curriculum, allowing them to use it for previewing material prior to class, supplementing other resources during lab, or reviewing material after sessions. These participants describe spreading out 3DVT use so that it is available to students when they are ready.

*Summary: Arrangement of Learning Experiences*

In summary, faculty discussed several different ways they arrange learning experiences involving 3DVT use. Some participants described using 3DVT earlier to help students preview material prior to other sessions, while others described how later use of 3DVT allows students to build on the understanding they bring into the session. Finally, other participants talked about spreading out 3DVT use to allow students access to the technology at times appropriate for their level of learning. Table 4.14 summarizes the subthemes related to how faculty arrange learning experiences involving 3DVT use.

Table 4.14: Summary of Arrangement of Learning Experiences Subthemes

| **Arrangement of Learning Experiences** | |
|---|---|
| Early use of 3DVT | Faculty discussed how use of 3DVT early in the learning process can allow students to preview material before other types of sessions and increase adoption of the technology. |
| Later use of 3DVT | Some faculty discuss how other learning experiences are used to help students build a base of understanding before they use 3DVT. |
| Spread out use of 3DVT | Faculty discuss how 3DVT use is spread across learning experiences so students can benefit from accessing it when needed depending on their level of learning. |

**Summary: Sequence**

Thematic analysis generated two major themes describing the sequence of 3DVT use in the curriculum, including three subthemes related to how faculty arrange subject matter taught with 3DVT and three subthemes related to how faculty arrange 3DVT learning experiences. Participants described arranging content taught using 3DVT according to three organizational schemes: a) anatomical, b) procedural, and c) progressive learning. Participants also described how learning experiences were arranged to include a) early use of 3DVT, b) later use of 3DVT, and c) spread out use of 3DVT. Figure 4.15 provides a diagram illustrating the themes and subthemes which describe how faculty sequence 3DVT use.

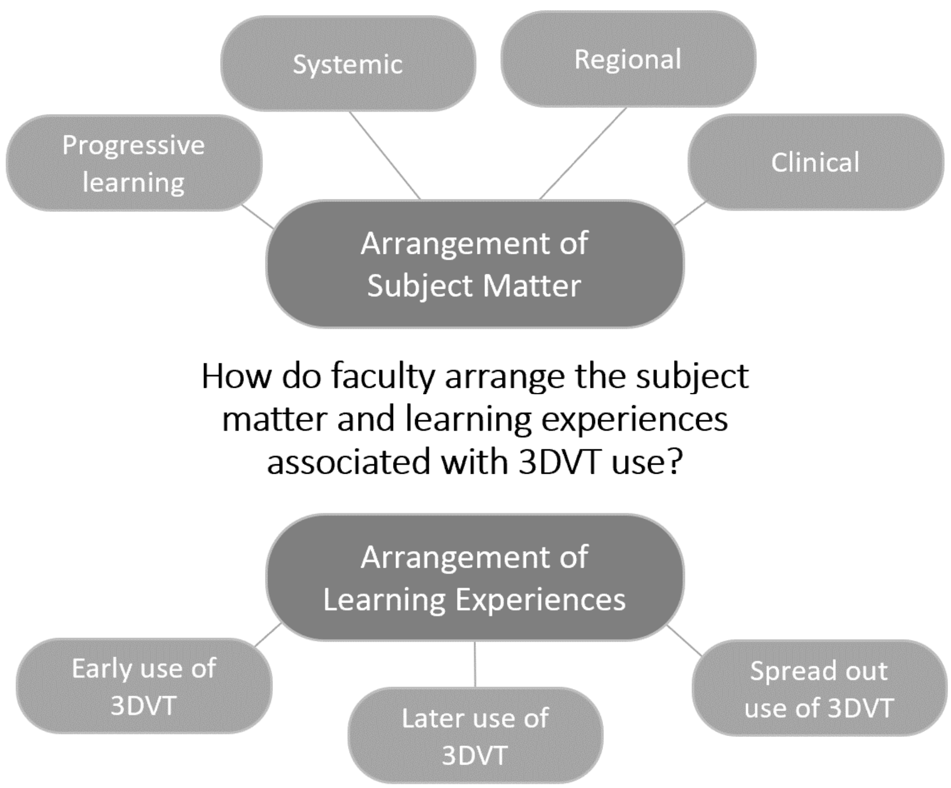



Figure 4.15: Themes and Subthemes of 3DVT Use Related to Sequence

*Instructional Processes*

Lattuca and Stark (2011) define instructional processes as “the instructional activities by which learning may be achieved” (p. 5). Instructional processes represent an important component of the curriculum because student learning is influenced by instructional strategies. Faculty use of 3DVT was examined in relation to instructional processes by exploring the different learning activities that included 3DVT use. In exploring this academic plan element, themes generated from analysis were used to answer the following research sub-question:

- Into what type of instructional processes are 3DVTs incorporated?

In their discussion of instructional processes Lattuca and Stark (2011) refer to an article by Weston and Cranton (1986) who describe four categories of instructional methods. Since the data appeared to fit well into this categorical scheme it was used to organize the themes for instructional processes. Thematic analysis resulted in ten subthemes representing the types of instructional activities into which faculty described incorporating 3DVT use. These subthemes were organized into four major themes based on Weston and Cranton's (1986) categories of instructional methods: 1) Instructor-Centered, 2) Interactive, 3) Experiential Learning, and 4) Individualized Learning. The following sections discuss each of the four themes and related subthemes, before a final section summarizes the themes related to instructional processes.

**Instructor-Centered**

Many participants described incorporating 3DVT use into instructor-centered teaching methods. Weston and Cranton (1986) define instructor-centered methods as those where "the teacher is primarily responsible for conveying information to a group of students" (p. 260). This includes teaching activities where the instructor leads the session, and communication is primarily one-way. Faculty who described instructor-centered instructional processes discussed using 3DVT for a) lecture, b) demonstration, and c) questioning.

*Lectures*

Some of the participants described using 3DVT to present during lectures. These participants described using 3D visualizations during sessions that include delivering a talk to a group of students, who largely act as passive participants. For example, one participant described incorporating the use of a 3D application during didactic sessions:

> It really wasn't until this past year that myself, and two other faculty, started using [the 3D application] in the lecture hall; using animations, using the software itself. So, basically going from a PowerPoint presentation, saying ah okay, let's go and jump and see that in the 3D version.

This participant described using 3DVT to supplement traditional presentations slides, allowing for additional clarification of concepts. Another participant described including students in the use of 3DVT during lecture sessions:

> They have [the 3D application] as an attachment to where I can sync the image that I have on my screen, I can sync it to the iPad version. So, if the kids come into lecture and they have their iPads with them, and they pull up [the 3D application] on their iPads and I specifically want to talk about a specific image, then I can cast that out to them on their iPads.

This participant explained how students are able to follow along during the session on their own devices. These participants described using 3DVT during lecture sessions to supplement information presented in slides and put resources directly in students' hands.

*Demonstrations*

While some participants described incorporating 3DVT into lectures, others described using 3DVT for doing demonstrations. These participants use 3DVT in various contexts to illustrate concepts, or the application of concepts. One participant described using stereoscopic models to create demonstrations for undergraduate medical students:

> Almost every week we used to have a demo for all the different batches . . . First, I start off with the basics. So, when I do a sagittal section, I go to the right side, and I do it so quick, they should know that there is a liver around there . . . If I go to the left and see the spleen sometimes they are so confused about, what is that, that looks like a liver. And then I sweep it this way, right and left, and show them the liver, the size of it.

This participant led demonstrations and walked students through the anatomy of the abdomen by using the 3DVT to move around through different sections. Similarly, another participant described creating demonstrations during virtual lab sessions:

> I can, you know, do the sections that I want to show whatever I want to. So, I'm getting a lot better at using it. Changing the colors, that's always one that seems to be really good, tissue types . . . Now in our virtual lab we have a 3D capable projector . . . And of course, our students wear the 3D glasses when we do this.

This participant describes using the 3DVT to manipulate the colors and tissue densities seen in stereoscopic models during demonstrations. Both of these participants described using 3DVT to create demonstrations where they can alter the anatomy being displayed in real time.

*Questioning*

Questioning was another instructor-centered method into which some participants described incorporating 3DVT. Questioning occurs when the instructor directs questions to students, and it is often used in combination with other instructional methods. For example, one participant described embedding questions into lab sessions:

> And then you can ask questions, you know what structure attached testes to the scrotum. And what we're looking for is the gubernaculum, or the remnant of the gubernaculum, because of the embryological part that it plays in pulling the testes into the scrotal sac.

This participant incorporates questions into the steps of a virtual dissection lab that ask students to think further about the clinical importance of the structures they are seeing. Another participant described incorporating questions during demonstrations, asking students to think about the clinical implications of the shape of the arteries being seen. These participants used questioning during 3DVT use to get students thinking about the relevance of structures being viewed.

*Summary: Instructor-Centered*

While some of the participants described using 3DVT during instructor-centered activities, others felt this was not the best place to incorporate use of the technology. For example, one participant explained why they chose not to use 3DVT during lectures:

> In my lectures I don't use the 3D program. I could, but I personally haven't found that it would be that useful . . . Partly because I'm not very fast with it, and you can't really label the image . . . It makes that part of it trickier, so you end up having to kind of do it twice. Because you first show it in 2D and label them, and then you have to show it again in 3D. And you know time is always, not in abundance. So, we have 50 minutes for a lecture. And I can't run over because there’s someone following me.

This participant explains how the time constraints associated with lecture sessions preclude the use of 3DVT. Similarly, another participant described how time limitations factor into the decision to use 3DVT during lab sessions instead of demonstrations:

> If I have my first year students in there, where it's kind of a self-directed lab, right, where they have two iPads, I tell them one iPad have your lab guide, the other have [the 3D application] or something open, so that you can look at both. But if I'm directing something like that, where it's like, we got to get through this content in 15 minutes, we don't really have time to correlate the cadaver with the [3D application]. So, it's very much dependent on what the lesson may be.

These participants choose to use 3DVT in instructional processes that are less focused on the instructor, when more time is available for students to use the technology.

Overall, many of the participants described incorporating 3DVT use into instructor-centered methods, while a couple of participants expressed concerns about the time constraints of these methods. Some participants described using 3DVT as a supplementary resource during lectures, and others described using 3DVT to lead demonstrations. Finally, several participants described using questions to try and promote deeper thought related to the clinical relevance of structures seen in 3D visualizations. Table 4.15 summarizes the subthemes related to faculty use of 3DVT in instructor-centered teaching methods.

Table 4.15: Summary of Instructor-Centered Instructional Processes Subthemes

| **Instructor-Centered** | |
|---|---|
| Lecture | Faculty use 3D technology during sessions where students are passive participants as the instructor speaks to a group. |
| Demonstration | Instructors demonstrate a concept, application of a concept, or skill using 3D technology while students observe |
| Questioning | Faculty direct verbal questions to students during lectures or other processes involving the use of 3D technology |

**Interactive**

Some participants described incorporating 3DVT use into interactive teaching methods. Weston and Cranton (1986) define interactive methods as those that “utilize communication among students, as well as between the instructor and students” (p. 261). This includes teaching activities where student interaction and participation help facilitate learning. Faculty who described including 3DVT use in interactive instructional processes discussed using 3DVT for a) discussion, b) group projects, and c) peer-teaching.

*Discussion*

Discussion is a type of interactive teaching method that involves prompting students to converse with peers by asking them to share their thoughts on a topic or question. One participant described using 3DVT to facilitate student discussions during lab sessions:

> One other thing we do during this class, we have a case study where I get them all together at the beginning, I give them a little case outline . . . that sort of gets them thinking about things. They don't have that case ahead of time, it's used to engender conversation during the class.

This participant uses pathologies visible in the 3D models as the basis for case studies that students must discuss. This participant described how they hope including cases will get students talking about the anatomical basis of the disease and prompt them to share ideas in order to create a differential diagnosis.

*Group Projects*

Group projects are another interactive teaching method that one participant described incorporating the use of 3DVT into. Group projects are assignments that require students to work together to create a final product. One participant described how students could use 3D reconstructions from the CT scans of donors as one resource for creating pathology reports:

> We gave them normal scans then along with their cadaveric scans, and we encouraged them to use both to see the anatomy . . . At the end of the course, we require the students do a pathology report. And so, in that first year only about 10 to 15% of the students used the images of their bodies in their pathology reports. So, that was kind of our measure of how well they were buying into to using that. The second year that jumped considerably to over 50% of the students, and when you think that not all pathologies are readily imaged with the CT scan, we thought that was pretty darn good. And then this past year, it was actually upwards of about 70%

By assigning the pathology report project this participant encouraged students to work together studying the 3D scans of donors to look for abnormal anatomy.

*Peer-Teaching*

Finally, one participant described incorporating 3DVT use with peer-teaching. In this interactive teaching method students are actively involved in teaching and learning as they become responsible for filling the role of instructor. This participant described how peer-teaching was required during laboratory sessions with 3D tables:

> The other innovative thing that we did, since there are six students at each table when they rotate through it, I have two students at each of those tables teach the class. Now, what we're doing is we're throwing the onus of learning onto them. And the students at first hate it because this is not premed stuff, where it's just tell me what I need to know so I can regurgitate it on the test. This is, I have to learn it, so I can teach it to my fellow students . . . They prepare it, they learn it, and they're ready when they come in on Monday morning. So that's a big step in the right direction and that really gets into the need to have students take responsibility for things, get ready to teach, and work with one another.

By adding peer-teaching to the use of the 3D tables this participant hopes to encourage students to work together and take on the responsibility of preparing.

*Summary: Interactive*

In summary, participants described incorporating 3DVT use into three types of interactive teaching methods. Interactive instructional processes utilize interaction between individuals to create an environment where the students are active participants in learning. One participant described using 3D case studies to stimulate group discussions about clinical anatomy. Another participant assigned group projects where students were able to use 3D scans of their donors in pathology reports. Finally, one participant described implementing peer-teaching centered on 3D interactive tables. Table 4.16 summarizes the subthemes related to faculty use of 3DVT in interactive teaching methods.

Table 4.16: Summary of Interactive Instructional Processes Subthemes

| **Interactive** | |
|---|---|
| Discussion | Students discuss an issue, question or topic with peers in a class or group setting. |
| Group projects | Students work with peers on completion of a project which can include the use of 3D technology. |
| Peer-teaching | Students are responsible for teaching to material to their peers during the use of 3D technology |

**Experiential Learning**

Many participants described incorporating 3DVT use into experiential learning methods. Weston and Cranton (1986) explain that experiential learning is an instructional method where "teaching and learning take place in settings other than the classroom or in simulations of the natural settings" (p. 263). This includes teaching activities where students perform tasks in real or simulated settings, while under the observation of an instructor. Participants described using 3DVT in the following types of experiential learning settings: a) clinical, b) simulation, and c) laboratory.

*Clinical*

Several participants described clinical experiential learning methods where 3DVT was used in conjunction with patient care. Clinical teaching occurs when the learner performs tasks in a natural setting and receives feedback from the instructor who observes. One participant described how 3D models are used during patient care in a nuclear medicine residency program:

> Let's say a patient comes in and probably one of the more common things that I have is a particular scan looking for tumor imaging. And the scan is done basically from the level of the eyes to about the mid thighs. So, we've got a good portion of the head and neck, torso, and proximal lower extremities, to review and the residents will typically look at a MIP image, it's a maximum intensity projection, it's a rough 3D projection that we can spin around real quickly to get an idea where the abnormal areas are. But once they've looked at that, they will look at the various slices, basically from head to thigh to check and see where the abnormal areas are.

These residents use 3D projections during the interpretation of patient scans while someone oversees them to ensure they correctly interpret the normal versus abnormal distribution of tracers. Another participant describes why it is important to combine the use of virtual 3D technologies with clinical experiences:

> I think the most effective way that we've seen them used is really in conjunction with more traditional teaching methods. The biggest thing to pair them with obviously, is real life patient care, because that's ultimately the goal. We're doing the VR specifically with the goal of translating it into safer patient care. And so if you never make that

> translation and you never allow the learner to sort of make the connection between what they're doing in VR and what they're going to be doing in the operating room, in the endosuite, or on the ward of the emergency department, there's sort of a failure of your primary goal there, of why you're even using VR to begin with.

This participant explains how they believe connecting virtual training with patient care is necessary to help students see the context of what they are learning.

*Simulation*

Simulations are another type of experiential learning method participants described using. Participants described using 3D simulations to recreate clinical scenarios or procedures so that learners could practice the application of knowledge and skills in safe environments. For example, one participant described how VR simulations were first implemented for teaching surgical skills:

> VR simulators first came about with a thought that okay, how do we teach surgeons general principles like the fulcrum effect, if I move my hand down, the tip of my instrument will move up, and how do I gauge distance on a screen that doesn't present three dimensional information to me. And so that was your original goal of doing VR laparoscopy.

This participant went on to explain how newer VR simulators are used not only for teaching surgical skills, but also training students to think about surgical approaches and how to identify structures relevant to these approaches.

Another participant described using simulations in an ophthalmology program where virtual patients allowed residents and medical students to review anatomy of the eye, as well as practice examination and operative skills. This participant described how the instructional method used for teaching second year medical students shifted from an instructor-centered approach, to an experiential learning approach:

> It's a class of 150–260 students that would be broken up into four groups. So, on two different days, two subsequent days, our eye clinics used to be shut down, and no patients were seen. There would be one attending, one educator there, and then you would get six, seven residents and you had, I think two hours to teach them everything. Because there were no patients there it's just normal exams, and you're showing them your tools. And it was not very structured, because you had no idea what each instructor was doing, what was being taught. So instead, now, we go to the simulation center . . . And we have nobody sitting idle, it's kind of like a round robin, we keep them busy for two hours. And the feedback has been really good because again, they got practice, they practice the same thing in different ways, multiple times.

This participant explained how simulations were used to standardize learning for large groups of students and provide learners with the opportunity to practice examination skills in clinical like settings.

#### *Laboratory*

The last type of experiential learning method faculty described incorporating 3DVT use into was laboratory sessions. Laboratory teaching methods give students a space where they can practice and learn in a realistic, but controlled setting. Participants described integrating 3DVT into laboratory sessions as the primary learning tool used or as a supplementary tool to help students complete other activities. For example, one participant described providing students access to 3D models during dissection labs:

> We have computers and TV monitor screens in the lab. So [the 3D application] is available to be pulled up if you need it for lab dissection assistance . . . since there's only one of me, for 25 students, as we were working through the lab, I wanted them to have sort of another virtual instructor in case I couldn't be there, maybe they can check it out on [the 3D application] and get their answer themselves so that we could be most efficient in the lab.

This participant paired 3DVT use with dissections to help guide student learning when the instructor was unavailable. Another participant described using 3DVT prior to other laboratory activities:

> We did a second one, where we looked at fourth-degree vaginal tears from childbirth. We reviewed the anatomy of the vagina, the rectal sphincters, and those sorts of things so that we could look at how they're put together, the arteries and those sorts of things. And then what we did was we followed that with a beef tongue model where they can do a fourth-degree repair.

This participant used the 3D models to review the anatomy before having the residents actually practice the repair procedure. Finally, a couple of participants described using 3DVT as a stand-alone activity that students interacted with during laboratory sessions where they rotated through stations covering various topics.

*Summary: Experiential Learning*

In summary, participants described incorporating 3DVT use into three types of experiential learning methods. Faculty used 3DVT during clinical teaching to give learners opportunities to practice skills in real health care settings while under supervision. Faculty also described using 3D simulations to recreate clinical environments, allowing learners to practice skills and knowledge application without risk to patients. Finally, participants described using 3DVT during laboratory sessions, either paired with other activities such as dissection or as stand-alone activities. Table 4.17 summarizes the subthemes related to faculty use of 3DVT in experiential learning methods.

Table 4.17: Summary of Experiential Learning Instructional Processes Subthemes

| Experiential Learning | |
|---|---|
| Clinical | Faculty include the use of 3DVT while the learner performs work in a clinical setting. |
| Simulations | Faculty use 3D simulations to recreate clinical situations and/or procedures to provide learners an opportunity to practice skills and knowledge application in a safe environment. |
| Laboratory | Faculty often make 3D visualizations available in the lab space to help students while they complete other activities such as dissection or procedure practice. |

**Individualized Learning**

A couple of participants described incorporating 3DVT use into individualized learning methods. Weston and Cranton (1986) define individualized learning methods as those in which "students work directly with prepared materials at their own pace" (p. 261). While some instructors provide 3DVT for students to use on their own time as a supplementary study resource, faculty who use individualized learning techniques go a step further to create targeted modules that facilitate learning in specific areas. These participants describe incorporating 3DVT into a type of individualized learning Weston and Cranton (1986) call modularized instruction.

*Modularized Instruction*

Faculty participants that discussed modularized instruction, described using 3DVT to create learning activities or exercises that students complete on their own. For example, one participant described creating modularized instruction with a VR system:

> I knew right away that if I just gave the students the VR system and said, have fun, go do it, they would play for about two or three minutes and then say, what am I supposed to do? What should I do? So, I made a couple of self-directed learning modules . . . So, it says open up the knee

> joint module and find the medial collateral ligament. What is the attachment of that on the other end, what force pulls that taught, if it's torn what is likely also? You know, these types of questions where they have to be thinking about it, and not just oh, that's that ligament cool out of my way, actually describing why it's relevant, why they care about it.

This participant described focusing student attention on the clinical details of structures by creating custom learning activities students use with the VR system. Another participant described creating an interactive mobile application for students to review content after ophthalmology simulation sessions:

> And the mobile app is used for self-study, because you do it in the sim-center then how do you review everything that you just did? So, it's interactive, it's not stereo, but it's still 3D interactive. So that is available on their smart tablets and smartphones.

These participants use 3DVT for modularized instruction by creating exercises to facilitate student learning as they use the technology on their own time. Table 4.18 summarizes this subtheme related to faculty use of 3DVT in individualized learning methods.

Table 4.18: Summary of Individualized Learning Instructional Processes Subtheme

| Individualized Learning | |
|---|---|
| Modularized instruction | Faculty include the use of |

**Summary: Instructional Processes**

Thematic analysis generated ten subthemes representing the types of instructional processes faculty incorporate 3DVT use into. These subthemes were organized into four major themes according to Weston and Cranton's (1986) categories of instructional methods. Many of the participants described incorporating 3DVT into instructor-centered teaching methods. These participants talked about using 3DVT to a) supplement slides during lectures, b) lead demonstrations, and c) direct questions to students. Faculty participants also described incorporating 3DVT into interactive teaching methods. These participants described using 3DVT to prompt discussions using case studies, provide a tool for completion of group projects, and facilitate peer-teaching activities.

A number of faculty participants discussed implementing 3DVT use for experiential learning methods. These participants described using 3DVT for a) clinical teaching where students practice skills in health care settings, b) simulations where learners practice skills and knowledge application without risk to patients, and c) laboratory sessions where the technology is used alone or paired with other activities. Finally, participants described using 3DVT for individualized learning by creating modularized instructional activities that students completed on their own. Figure 4.16 provides a diagram illustrating the themes and subthemes that describe the types of instructional processes into which faculty incorporate 3DVT use.

*Evaluation*

Lattuca and Stark (2011) define evaluation as “the strategies used to determine whether decisions about the elements of the academic plan are optimal” (p. 5). Assessment of student learning and overall program assessment are both components of curriculum evaluation. Faculty use of 3DVT was examined in relation to evaluation by exploring how faculty use 3DVT for the assessment of student learning. Exploring the broader aspects of program evaluation was beyond the scope of this study. In exploring

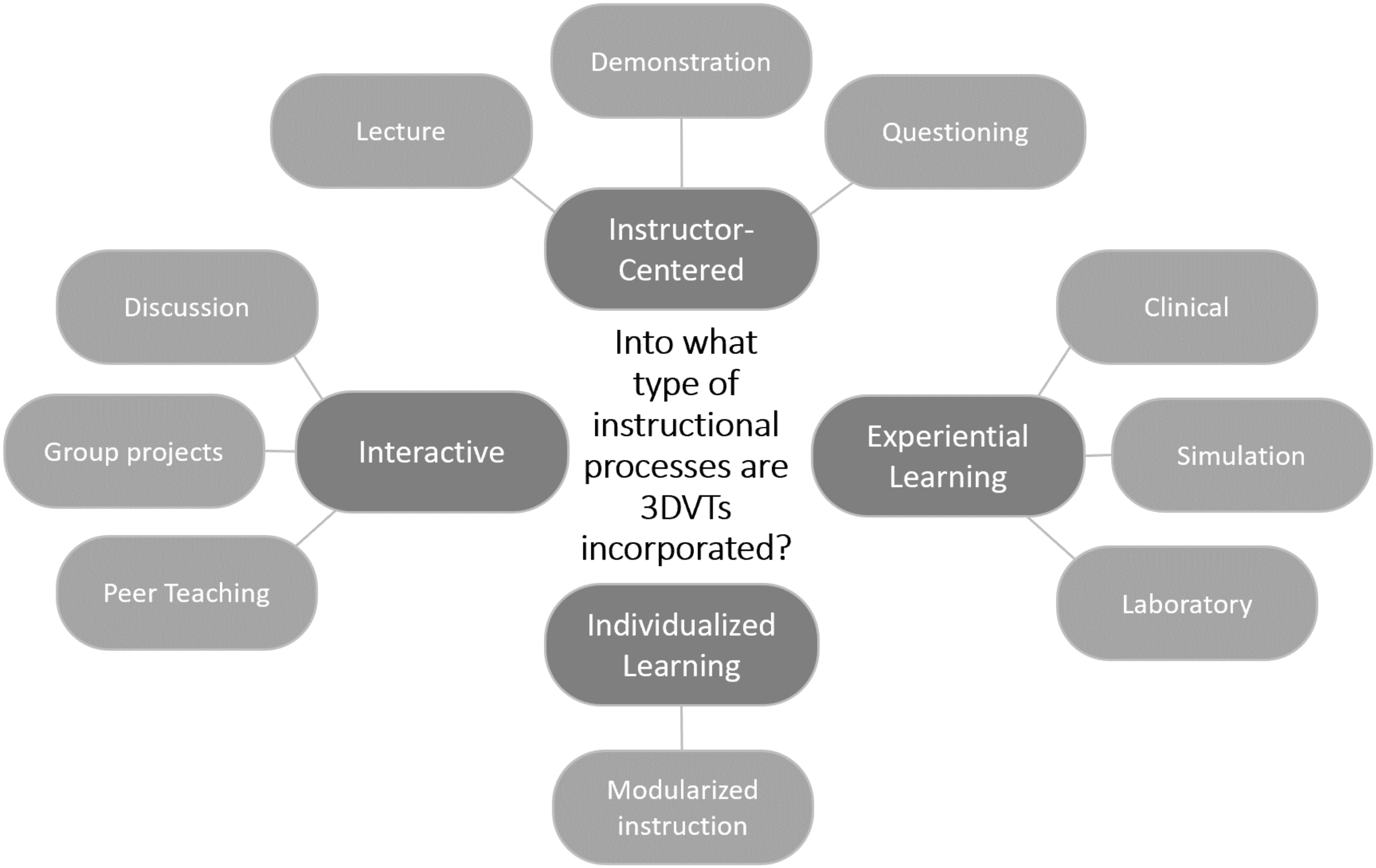



Figure 4.16: Themes and Subthemes of 3DVT Use Related to Instructional Processes

this academic plan element themes generated from analysis were used to answer the following research sub-question:

- How are 3DVTs used to evaluate student learning?

Thematic analysis resulted in five subthemes representing distinct ways faculty described using 3DVT for assessment of student learning. These subthemes were organized into two major themes describing how faculty used 3DVT for 1) Summative Assessment, and 2) Formative Assessment. In addition, a third theme emerged related to the limitations faculty described in using 3DVT for evaluating student learning. The following sections discuss each of the three themes and related subthemes, before a final section summarizes the themes related to 3DVT use for the evaluation of student learning.

### Summative Assessment

Summative assessment is used to evaluate student learning by measuring student proficiency at a particular time point, such as at the end of an instructional unit. Three participants described using 3DVT for summative assessment, where the technology helped form some part of an examination assessing overall student attainment of knowledge and skills. These participants described using 3D screenshots and simulation as part of the evaluation of student learning and skill acquisition.

#### *Screenshots*

Two participants described creating summative assessment items using screenshots taken of 3D visualizations. When asked if they used 3DVT to evaluate students one participant explained:

> We did this year, and boy were they hesitant. I gave them just static images, but on each practical exam six out of the 75 questions were all CTs . . . Like anything, it was a matter of just communicating with them, what the expectations are, what level we wanted them to be able to identify a structure from the CT or MRI.

This participant described how a specific portion of summative assessment items were structure identification questions created from screenshots of 3D CT scan reconstructions. Another participant similarly described how they use screenshots to create exam items:

> They have an exam coming up on Monday, and I actually will go through here, and this program allows us to save the images. So, I can save the cross-sectional image or the coronal image or the sagittal image. I can save this to my computer. I can import it into PowerPoint, I can put arrows on it. And then I can ask a variety of questions. I can ask them to name the structure. I can ask them the function of the structure. I can write a clinical question about the structure. So that's how we do some of the testing.

This participant explains how assessment items are created using screenshots showing cross-sections through 3D reconstructions. These exam items require students to not only identify structures, but also consider the function and clinical correlations of the structures seen in images.

*Simulation Examination*

Simulation was another way 3DVT use was incorporated into the summative assessment of student learning. One participant described an endoscopic simulation examination graduating surgical residents take:

> Our colonoscopy curriculum . . . was based on the fundamentals of endoscopic surgery examination, which is a test given in VR actually, it's a summative examination given in VR that is required to obtain certification from the American Board of Surgery.

This participant described how a standardized simulation exam is used as a summative assessment tool to determine if graduating surgical residents have obtained the fundamental knowledge and technical skills required for endoscopic surgery. However, this participant also warned of the challenges surrounding use of simulations for summative assessment:

> I think it's very tricky. I think there's still a lot of suspicion about whether or not these can be used. For formative assessment, I think it's okay. For summative assessment, I think we're still not quite there yet. The fundamentals of endoscopic surgery took about 10 years to validate. They started that process in the mid 2000’s. And it just got launched last year I think, I think last year may have been the first year that graduating residents had to take it for real . . .But it's an expensive process, a long process, but it's the right way to do it. And so I think that to sort of try to incorporate summative assessment with VR on a much shorter timeframe would be a little bit of a fool's errand, and I’d be a little worried about what types of metrics would come out of that, and whether those assessments would actually be meaningful.

This participant warns that using 3D simulation for summative assessment must be approached cautiously, and assessment metrics carefully designed to ensure proper evaluation of knowledge and skills.

*Summary: Summative Assessment*

Overall, very few participants described using 3DVT for summative assessment of student learning. Two of the participants described taking screenshots of 3D reconstructions of medical imaging scans to create exam assessment items. These exam questions asked students to identify structures, correlate structure with function, or demonstrate clinical knowledge related to structures indicated. Another participant described the standardized endoscopic simulation examination surgical residents must pass prior to certification. Table 4.19 summarizes the subthemes related to faculty use of 3DVT for summative assessment.

Table 4.19: Summary of Summative Assessment Subthemes

| Summative Assessment | |
|---|---|
| 3D screenshots | Faculty use static screenshots of 3D visualizations to create items for end of unit examinations. |
| Simulation examination | 3D simulation is used to evaluate learner proficiency |

**Formative Assessment**

Formative assessment is a part of the instructional process and is used to monitor student learning and provide feedback to inform continued learning. A number of participants described using 3DVT for formative assessment, where the technology helps provide students with information about their progress to guide improvements. These participants described using 3DVT for simulation, self-quizzing, and in-activity questioning as part of the on-going evaluation of student learning and skill acquisition.

*Simulation*

Two participants described using simulations for formative assessment, where the imitation of a situation or process provides students with feedback during the learning process. One participant described the benefits of using simulators in surgical training:

> I do think for formative assessment it's great, because I think it allows faculty or senior residents or fellows to observe students and junior residents, and see how they're able to sort of translate some of the more conceptual skills about surgery, and the concepts about dissection and thinking about retraction and things like that.

This participant describes how the simulator helps instructors observe learners in realistic scenarios, so that constructive feedback can be provided. Another participant uses virtual patients for formative assessment of students' eye examination knowledge and skills:

> That virtual patient, I can give it a pathology, it's unknown for the student, they don't know what pathology it is. And then I just call it patient A, patient B, patient C, and they have to go around and tell me what, because it's an actual exam, there's no description, they have to actually examine the patient and tell me what the pathology is . . . They come in, they examine, then we discuss it all. We go over the why, the anatomical correlation and stuff and then they go back and examine it again.

This participant describes how discussion follows use of the simulation to provide students with the chance to review their understanding before completing the eye exams again. These participants describe using simulators during the instructional process to provide students with formative feedback about their progress.

*Self-Quizzing*

A few of the participants described using 3DVT with self-quizzing features to provide students with another type of formative assessment. For example, one participant described creating a virtual recreation of a lab practical exam, or what this participant calls a "bell ringer":

> We just developed a headset based virtual reality app . . . and it's all based on stereo pairs of anatomy images . . . And you'll see that we have virtual pins stuck into the things. So, there's questions on a screen and they look, and then they answer just as you would in a bell ringer.

This participant claims that providing students with virtual practice questions that mimic the exam helps students to prepare for laboratory exams by giving them opportunities to assess their preparedness. Similarly, two other participants talked about using a 3DVT quiz feature to give students practice identifying structures and provide a way for them to test their understanding.

### *In-Activity Questions*

The last way participants described using 3DVT for formative assessment was by including in-activity questions. One participant described including questions in the laboratory activities students completed using 3D interactive tables, stating “You can see that I'm embedding lots of questions and other things to make it interesting but also things that I know they're going to be asked.” This participant described preparing students for clerkship rotations by including questions that required the type of knowledge application expected of them in the clinic. Another participant described including questions in self-directed learning modules that required students to consider the function and clinical relevance of structures viewed using VR. These participants incorporate formative assessment into learning sessions by adding questions into 3DVT activities. Participants contend these questions help students reflect on the content being covered and guide their learning as they work through activities.

### *Summary: Formative Assessment*

Overall, participants described several ways they use 3DVT for formative assessment of student learning. Two of the participants described using simulations to provide students with feedback regarding their progress. Other participants described using 3DVT with self-quizzing features to allow students to test their understanding of key anatomical concepts. Finally, several participants described incorporating questions into activities using 3DVT to test student knowledge and guide their learning. Table 4.20 summarizes the subthemes related to faculty use of 3DVT for formative assessment.

Table 4.20: Summary of Formative Assessment Subthemes

| Formative Assessment | |
|---|---|
| Simulation | Faculty use simulators to provide learners feedback through computer generated performance metrics or instructor feedback. |
| Self-quizzing | Many of the 3D technologies used by faculty have quizzing functions that allow students to assess their knowledge on their own time. |
| In-activity questions | Faculty can embed questions into lesson plans for students to discuss or require students to identify various structures on visualizations. |

**Limitations of Use in Assessment**

While some of the participants described using 3DVT for summative or formative assessment, many explained that the use of 3DVT for evaluating student learning was limited or nonexistent. Some of these participants discussed the challenges associated with assessing student learning, particularly the difficulty of creating assessments using 3DVT. Participants also described using methods other than 3DVT for assessing whether or not students obtain necessary knowledge and skills.

*Difficulty in Assessment*

Whether it was finding ways to accurately assess student learning or designing assessment using 3DVT, many of the participants described facing difficulties in assessment. One participant described the difficulty of assessing what students learn through the use of 3DVT:

> I don't think the test scores are adequate. Because these are smart people, they're probably going to pass the exam if they do or do not do this. I think a better way of looking at this is 'what did they retain when they get into their third year?' But how do I assess that? And I just don't know the answer here, I'm still looking for ways of doing that. I think everybody's struggling with that. I think everybody's struggling with that in the standpoint of just general anatomy too. You know, how do you assess what they retain because that's really what the important part is here. And it's easy to memorize. But what do they retain and how do they work that into their clinical practice, that's the key.

This participant, and others, expressed how difficult it can be to design assessments which accurately evaluate what students learn from 3DVT use and how well this knowledge is retained over extended periods of their training. Similarly, another participant described the challenge of implementing simulators in a way that ensured reliable assessment measures:

> Some of the things that we really had to figure out sort of early in the process of VR is really getting an understanding of what does it mean to be a validated quote unquote simulator? Does that mean that we are looking for a simulator that looks and feels like a surgery? Are we looking for a simulator that can more accurately sort of separate out, this is the performance of a medical student, this is the performance of the third-year resident, and this is the performance of experienced attending? And it's really understanding that just because you put in a bunch of metrics into the computer system, doesn't mean that those metrics can actually distinguish these different levels of learner or surgeon. And so, then it was really thinking about, okay, well, we actually really need to redesign the metrics to make sure that we're measuring what we say we're measuring.

This participant describes the difficulty of designing simulators so that the assessment metrics accurately measure meaningful improvements in performance.

Other participants described difficulties in finding ways to integrate 3DVT use into existing assessment methods. For example, one participant described the problems associated with using a 3D reconstruction program for assessment:

> I haven't used [the 3D application] in any of our testing, because we use exam soft to do testing on it for the students . . . Our version does not allow the incorporation of video clips . . . So, if I want to open up [the 3D application], for example, and show the students a video clip of somebody's CAT scan, I can do that. But I have to make it a still image, I have to take a screenshot of it if I really want the students to use it. Or if I want to use it on an exam. If I had the ability to save all this as a video, and test them on the video, I would.

This participant describes how limitations of the testing software restrict how 3D visualizations can be used for creating exam items.

*Use of Other Methods*

While some participants described difficulties in assessment that limited the use of 3DVT, other participants described using alternative methods for assessing students. For example, one participant describes the type of multiple-choice questions used for exams:

> We have a number of multiple-choice questions that we give as part of our exams, that we’ve used over the years, that requires a student to think beyond the 2D. So, for example, a stab wound just to the right of the sternum, fourth intercostal space, what part of the heart is it going through. So, using those kinds of questions requires them to think a little more three-dimensionally.

Instead of 3DVT, this participant uses questions related to the knowledge of structure relationships to assess students’ 3D understanding of anatomy. Similarly, other participants explained that multiple-choice standardized exams are used as the primary assessment of student learning. Several participants also described including imaging questions on lab and written exams, which asked students to identify structures in labelled MRI or CT scans.

Performance evaluation was another assessment method participants described using instead of 3DVT. These participants described evaluating students by having an instructor oversee them as they performed work in a health care setting. For example, one participant described how they determine if residents have learned the pertinent information from a patient case:

> The residents typically take the first stab at writing the report . . . So, when I evaluate these reports, I get a pretty good idea of how thoroughly the resident has looked at it. What they're thinking in terms of the disease process, what's going on with the patient, how sensitive they are in terms of picking up the abnormalities, and then at the very end, putting all this information together into a few sentences to try and sum it up all together. So that's kind of how I test it.

These residents are allowed to perform as they would during normal patient care, and then they are evaluated on their ability to accurately write up the radiology report. Another participant described a similar system of evaluating performance for surgical residents who are assessed based on their abilities in the operating room.

*Summary: Limitations in Use of Assessment*

In summary, the use of 3DVT for assessment of student learning was limited. Many of the participants described difficulties in assessment surrounding 3DVT use. These participants described difficulties both finding ways to accurately assess student learning and trying to use 3DVT for assessment. Additionally, a number of participants described using more traditional assessment tools when evaluating student learning. Instead of 3DVT, these participants described assessing students using multiple choice questions, standardized exams, imaging identification questions, and performance evaluations. Table 4.21 summarizes the subthemes related to faculty use of 3DVT for formative assessment.

Table 4.21: Summary of Limitations of Use in Assessment Subthemes

| Limitations of Use in Assessment | |
|---|---|
| Difficulty in assessment | Faculty face challenges in adequately evaluating student learning, and have difficulty incorporating 3DVT into assessment tools. |
| Use of other methods | Instead of using 3DVT for assessment, faculty rely on more traditional methods of evaluating student learning. |

**Summary: Evaluation**

Thematic analysis generated two major themes that describe how faculty use 3DVT to evaluate student learning. Several participants talked about using 3DVT for summative assessment, where 3D screenshots and simulations were used as a part of evaluating student proficiency at a particular point in time. Participants also described creating formative assessment by using 3DVT for simulation, self-quizzing, and in-activity questions. These participants used 3DVT to provide students with information about their progress and inform continued learning. Finally, a third theme emerged which describes how the difficulties of assessment and faculty use of other assessment methods create limitations in the use of 3DVT for evaluating student learning. Figure 4.17 provides a diagram illustrating the themes and subthemes which describe how faculty use 3DVT for evaluation of student learning.

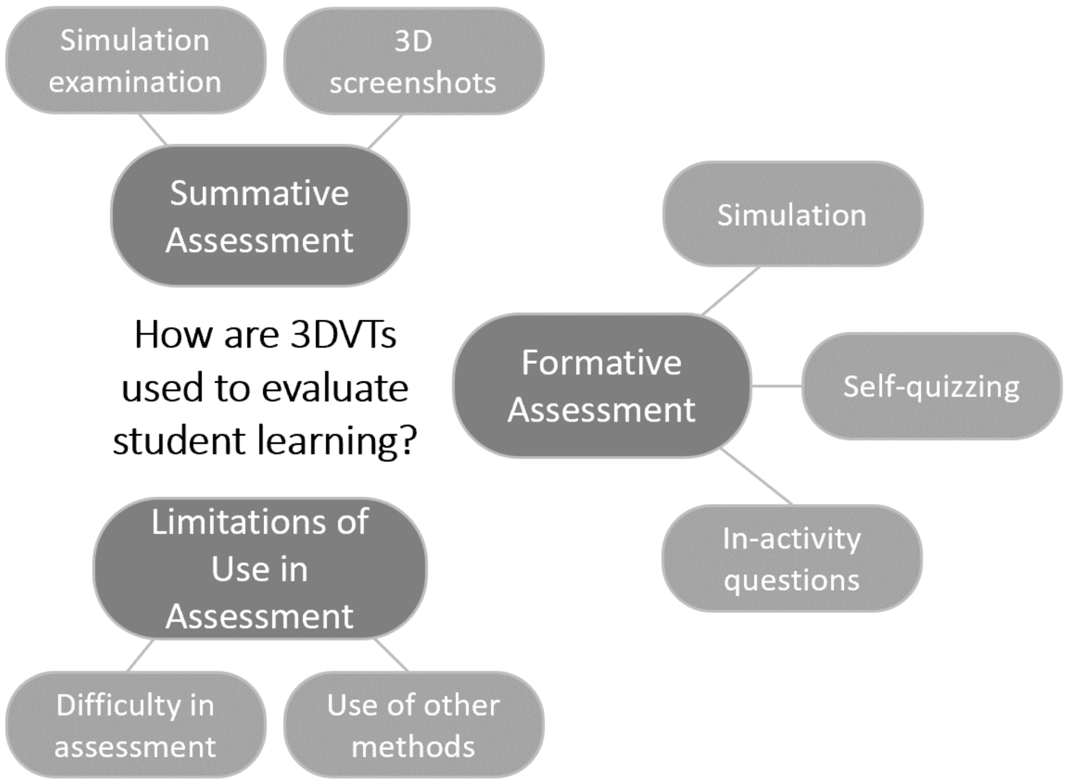



Figure 4.17: Themes and Subthemes of 3DVT Use Related to Evaluation

*Summary of Themes*

A thematic analysis was used to explore how faculty use 3DVT for anatomy education in the medical curriculum. Lattuca and Stark's (2011) academic plan model provided a guiding framework for examining faculty use of 3DVT in relation to individual elements of the curriculum. Emerging themes were organized into categories based on the academic plan element they addressed: 1) Instructional Resources, 2) Purposes, 3) Content, 4) Sequence, 5) Instructional Processes, or 6) Evaluation. Together the themes for each element provide an overall framework for understanding how faculty use 3DVT within the medical curriculum. Figure 4.18 provides a diagram illustrating the themes and subthemes which describe how faculty use 3DVT in the medical curriculum.

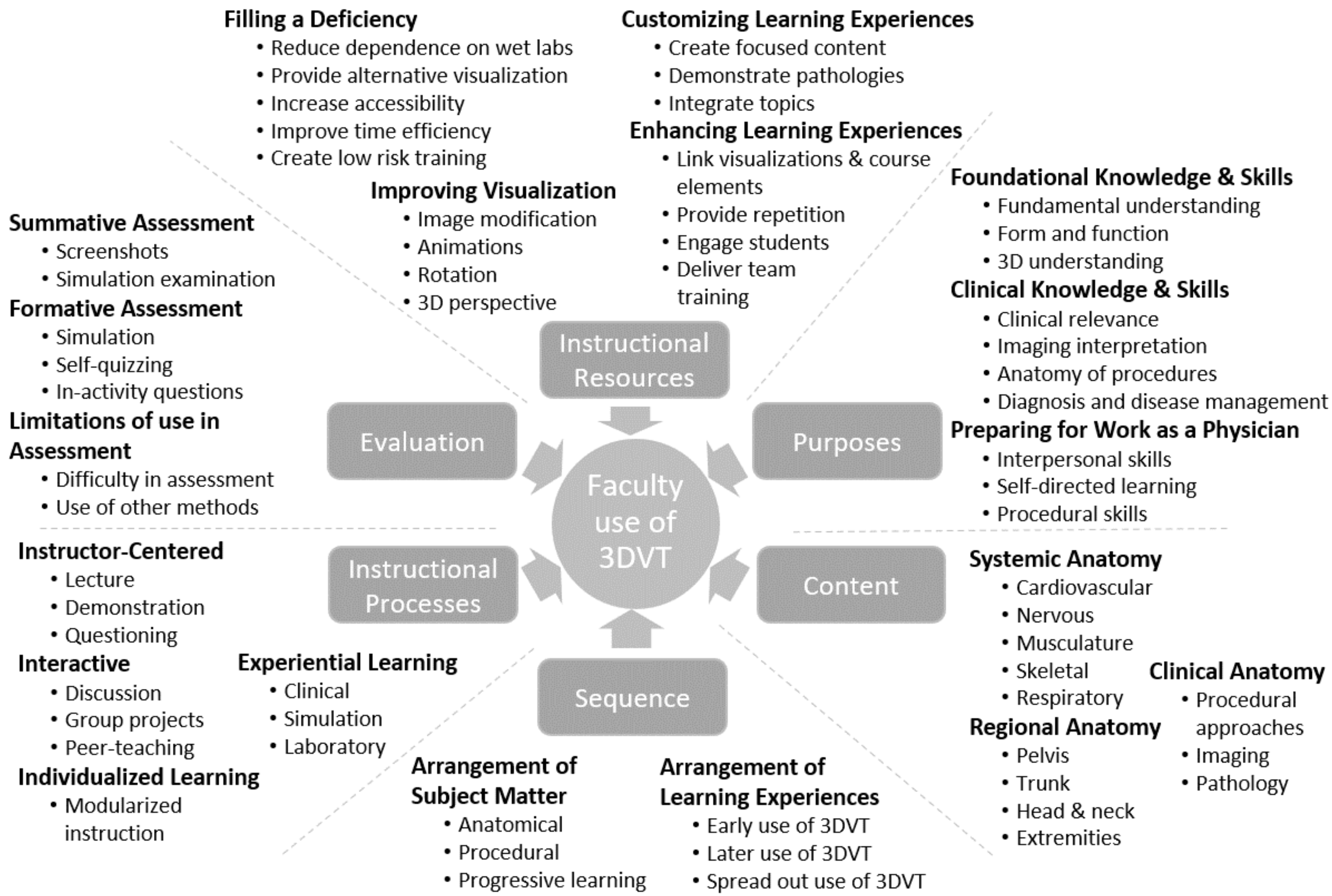



Figure 4.18: Themes and Subthemes Representing Faculty Use of 3DVT in the Medical Curriculum

**Comparing Faculty 3DVT Use Across the Curriculum**

Upon completion of the thematic analysis exploring faculty use of 3DVT the data was examined to address the second research question related to comparing use of 3DVT across levels of the medical curriculum. The quotes coded for each subtheme were explored to find similarities and differences in how preclinical and postgraduate faculty participants discussed the use of 3DVT. Although neither clinical participant used 3DVT for teaching, quotes from these participants describing the potential for 3DVT use in clinical clerkships were used for comparison. Table 4.22 presents the similarities and differences in 3DVT use that were found related to each academic plan element. Check marks indicate which levels of the curriculum had representative quotes from participants discussing that subtheme. In addition, notes indicate any differences in how participants of different levels discussed the various subthemes.

Table 4.22: Similarities and Differences of 3DVT Use

<table>
<tr><th colspan="4">INSTRUCTIONAL RESOURCES</th></tr>
<tr><th>Filling a Deficiency</th><th>Preclinical</th><th>Clinical</th><th>Postgraduate</th></tr>
<tr><td>Reduce dependence on wet labs</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Provide alternative visualization</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td rowspan="2">Increase accessibility</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Focus was on ability for students to take resource home or with them moving forward into clinical settings</td><td colspan="2">Focus was on providing an alternative tool for studying examination or operative procedures when access to patients is inconvenient or not feasible</td></tr>
</table>

| | | | |
|---|---|---|---|
| Improve time efficiency | ✓ Focus was on making lab time more efficient | | ✓ Focus was on efficiency of student learning |
| Create low risk training | | | ✓ |
| **Improving Visualization** | | | |
| Image modification | ✓ | | ✓ |
| Animations | ✓ | | Mentioned by one participant that also teaches other levels, who didn't specify which level animations were used with |
| Rotation | ✓ | | ✓ |
| 3D perspective | ✓ Mainly discussed by preclinical participants | | ✓ |
| **Customizing learning experiences** | | | |
| Create focused content | ✓ Mainly preclinical participants discussing use for customizing lab sessions | | ✓ One participant discussed customizing sessions walking residents through procedures |
| Demonstrate pathologies | ✓ Focused more on showing clinical relevance and comparing abnormal to normal anatomy | | ✓ Focused more on specific pathologies and how they are identified and treated |
| Integrate topics | ✓ | | |

| Enhancing learning experiences | | | |
|---|---|---|---|
| Link visualizations & course elements | ✓ | | ✓ |
| Provide repetition | ✓ One description of building student 3D understanding through repetition of going through layers | | ✓ Mainly discussion of trainee repetition of exams or procedures |
| Engage students | ✓ | | ✓ |
| Deliver team training | | | ✓ |
| **PURPOSES** | | | |
| **Foundational Knowledge & Skills** | | | |
| Fundamental understanding | ✓ Discussed extensively by preclinical participants | ✓ One discussed head & neck anatomy that was added to clinical years | ✓ Discussion primarily focused on review of anatomy specific to region of specialty |
| Form and function | ✓ Mainly discussed by preclinical participants | | ✓ |
| 3D understanding | ✓ | | ✓ |
| **Clinical Knowledge & Skills** | | | |
| Clinical relevance | ✓ Mainly preclinical participants discussing helping students see the importance of what they are learning | ✓ One participant described how students should learn to view 3D echo-cardiography and understand its clinical importance | ✓ Some description of tying anatomy review into clinical context they are working in |

| | | | |
|---|---|---|---|
| Imaging interpretation | ✓ Focus is on learning to correlate normal anatomy with imaging | | ✓ Focus is on learning to read patient imaging and identify abnormal anatomy |
| Anatomy of procedures | ✓ Minimal discussion focused on relating general anatomy being learned to a variety of procedures | ✓ Emphasis on understanding of anatomy specific to certain operative procedures common in specialty | ✓ |
| Diagnosis & disease management | | ✓ | ✓ |
| **Preparing for Work as a Physician** | | | |
| Interpersonal skills | ✓ | ✓ | ✓ |
| Self-directed learning | ✓ | | ✓ |
| Procedural skills | | | ✓ |
| **CONTENT** | | | |
| **Systems** | | | |
| Cardiovascular | ✓ Focus on general knowledge of blood vessels and heart structures | | ✓ Focus on blood vessels of specific regions related to procedures |
| Nervous | ✓ Focus on general knowledge of pathways and innervations | | ✓ Focus on testing for lesions and structures related to specific procedures |
| Muscular | ✓ Mainly discussed by preclinical participants | | ✓ |

| | | | |
|---|---|---|---|
| Skeletal | ✓ | | ✓ |
| Respiratory | | | ✓ |
| **Regions** | | | |
| Pelvis | ✓ Mainly preclinical participants discussing general pelvic anatomy | | ✓ One participant described teaching anatomy related to OBGYN operations |
| Trunk | ✓ | | ✓ |
| Head and neck | ✓ | | ✓ Focused on specific anatomy related to various procedures |
| Extremities | ✓ | | |
| **Clinical Anatomy** | | | |
| Procedural approaches | | ✓ One participant described potential of 3D for teaching students about core operations | ✓ Discussed extensively with focus on teaching anatomy as it is encountered during procedures |
| Imaging | ✓ Extensive discussion of teaching imaging interpretation; particularly related to reading cross-sections | | ✓ One description of teaching patient imaging interpretation in a radiology focused specialty |
| Pathology | ✓ Focus on showing general pathologies related to anatomy being learned | | ✓ Focus on teaching about pathologies specific to specialty |

| SEQUENCE | | | |
|---|---|---|---|
| **Arrangement of Subject Matter** | | | |
| Anatomical | ✓ | | |
| Procedural | | | ✓ |
| Progressive learning | | | ✓ |
| **Arrangement of Learning Experiences** | | | |
| Early use of 3DVT | ✓ Primarily focused on early use as a means to prepare students prior to lab sessions | | ✓ Focused on use to teach basic steps prior to procedures and normal anatomy prior to learning how to dissect out specific pathologies |
| Later use of 3DVT | ✓ | | ✓ |
| Spread out use of 3DVT | | ✓ One participant described potential of 3D for previewing and reviewing anatomy of surgeries encountered | ✓ |
| **PROCESSES** | | | |
| **Instructor-Centered** | | | |
| Lecture | ✓ | | ✓ |
| Demonstration | ✓ | | |
| Questioning | ✓ | | |
| **Interactive** | | | |
| Discussion | ✓ | | |

| | | | |
|---|---|---|---|
| Group projects | ✓ | | |
| Peer-teaching | ✓ | | |
| **Experiential Learning** | | | |
| Clinical | | ✓<br>One participant mentioned how students may see 3D echo-cardiography done during their rotations | ✓ |
| Simulations | | | ✓ |
| Laboratory | ✓ | | ✓ |
| **Individualized** | | | |
| Modularized instruction | ✓ | | ✓ |
| **ASSESSMENT** | | | |
| **Summative Assessment** | | | |
| 3D Screenshots | ✓ | | |
| Simulation examination | | | ✓ |
| **Formative Assessment** | | | |
| Simulation | | | ✓ |
| Self-quizzing | ✓ | | *One participant mentioned the potential for future addition of a quizzing function |
| In-activity questions | ✓ | | |
| **Limitations of Use in Assessment** | | | |
| Difficulty in assessment | ✓ | | ✓ |

| | | | |
|---|---|---|---|
| Use of other methods | ✓ Participants described using labeled medical images, as well as multiple-choice and standardized exams | | ✓ Participants primarily described using performance evaluations, and one mentioned multiple-choice exams |

**Questionnaire**

Upon completion of the thematic analysis a development phase was undertaken to create a questionnaire for future research examining the prevalence of the themes found in this study. The process used to build the questionnaire was based on Creswell and Clark's (2017) approach for the development of a quantitative tool based on qualitative findings. The authors describe how the qualitative findings are used to determine the constructs to be addressed and recommend generating survey items based on participant language whenever possible. During this process the themes resulting from the qualitative analysis are used to create survey items grounded in the perspectives of faculty participants. The creation of a questionnaire based on the views of participants who teach using 3DVT increases the likelihood that it will be seen as relevant to those in medical education.

The academic plan elements explored in this study were used to organize the survey into six sections, and the themes resulting from the qualitative analysis formed the constructs for each of these major categories. Next, the subthemes and representative quotes related to each subtheme informed the creation of specific survey items addressing each construct. Table 4.23 provides a joint display showing how the subthemes from the qualitative phase correspond to specific survey items. The resulting survey included 77 items representing 19 thematically defined dimensions describing faculty use of 3DVT (Appendix C). The organization of the survey allows it to be implemented in its entirety or by individual sections that examine faculty use of 3DVT as it relates to specific components of the curriculum.

After items were generated a complete copy of the questionnaire was sent to participants for the member check. Participants were sent a link to a survey that included questionnaire items along with open response boxes requesting feedback on item clarity and overall survey quality. Participant feedback was used to refine questions, for example clarifying the difference between efficiency of student learning, and efficiency of learning sessions. Overall, participants indicated they felt the survey encompassed important aspects of 3DVT use. The questionnaire was also sent to a survey expert for review, and the feedback received was used to further refine questions to improve clarity and readability of items.

Table 4.23: Joint Display of Subthemes and Representative Questionnaire Items

| Instructional Resource | |
|---|---|
| **Themes**<br>& Subthemes | **Representative Questionnaire Items** |
| **Filling a deficiency** | Considering any 3DVT that you have used for medical education, how much do you agree or disagree with the following statements? |
| Reduce dependence on wet labs | • I have used 3DVT to reduce the need for wet labs (e.g. replacing or supplementing cadaver and/or animal skills labs). |
| Provide alternative visualization | • I have used 3DVT to provide an alternative way for students to visualize anatomy. |

| | |
|---|---|
| Increase accessibility | • I have used 3DVT to increase student access to tools for learning. |
| Improve time efficiency | • I have used 3DVT to increase the efficiency of student learning (i.e., reduce leaning time).<br>• I have used 3DVT to make time in learning sessions more efficient (i.e., reduce procedural time). |
| Create low risk training | • I have used 3DVT to create learning opportunities that minimize risks to patients. |
| **<u>Improving Visualization</u>** | How useful are each of the following 3DVT functionalities for providing students with an ideal visualization of the anatomy being learned? |
| Image modification | • Adding or removing structures<br>• Altering transparency<br>• Altering coloration<br>• Isolating specific structures |
| Animations | • Animations |
| Rotation | • Rotation |
| 3D perspective | How useful is the 3D perspective provided by 3DVT for giving students an ideal visualization of the anatomy being learned? |
| **<u>Customizing learning experiences</u>** | To what extent do you use 3DVT to do the following? |
| Create focused content | • Create customized learning materials (e.g. alter visualizations to focus on relevant content, exclude structures not specific to the lesson, etc.)<br>• Create customized lesson plans (e.g. using the technology to guide students through sequential steps) |
| Demonstrate pathologies | • Show students pathology |
| Integrate topics | • Integrate content from other basic science areas of the curriculum (i.e. histology, physiology, etc.)<br>• Integrate clinical content with anatomy being taught. |
| **<u>Enhancing learning experiences</u>** | How much do you agree or disagree with the following statements about 3DVT use in your curriculum? |
| Link visualizations & course elements | • The 3D visualizations are frequently linked to other instructional resources (textbooks, informational videos, teaching modules etc.) |

| | |
|---|---|
| | • The 3D visualizations are frequently linked to additional content (i.e., structure information, clinical correlates, or medical images). |
| Provide repetition | • 3DVT is used because it allows for easy repetition of activities. |
| Engage students | • 3DVT is used to engage students in learning experiences. |
| Deliver team training | • 3DVT is used with multiple people for team training. |
| **Purposes** | |
| **Foundational Knowledge & Skills** | How important to you are the following student learning outcomes from the use of 3DVT? |
| Fundamental understanding | • Fundamental understanding of anatomy (i.e., the identification structures and description of the human form and its organization) |
| Form and function | • Knowledge of form and function (i.e., the ability to connect human structure with how things work and why things happen) |
| 3D understanding | • 3D understanding of anatomy (i.e., visuospatial understanding of the human form, how the body is arranged, and the 3D relationship of structures) |
| **Clinical Knowledge & Skills** | |
| Clinical relevance | • Understanding the relevance of anatomy in the context of clinical settings |
| Imaging interpretation | • The ability to apply anatomical knowledge to the interpretation of medical imaging |
| Anatomy of procedures | • Knowledge of procedural anatomy (understanding anatomy as it relates to specific procedures so that structures can be safely examined, accessed, or navigated around) |
| Diagnosis & disease management | • Understanding of diagnosis and disease management |
| **Preparing for Work as a Physician** | How important is student achievement of the following skills during their use of 3DVT? |
| Interpersonal skills | • Teamwork<br>• Leadership<br>• Communication |
| Self-directed learning | • Self-directed learning |
| Procedural skills | • Procedural (competence in the physical and practical skills of clinical care) |

| Content | |
|---|---|
| **Systems** | To what extent do you cover the following content areas using 3DVT? |
| Cardiovascular | • Heart<br>• Blood vessels |
| Nervous | • Peripheral nerves<br>• Central nervous system |
| Muscular | • Muscles |
| Skeletal | • Bones |
| Respiratory | • Respiratory structures |
| **Regions** | To what extent do you cover the following regions using 3DVT? |
| Pelvis | • Pelvis |
| Trunk | • Abdomen<br>• Thorax |
| Head and neck | • Head and neck |
| Extremities | • Extremities |
| **Clinical Anatomy** | To what extent do you cover the following topics using 3DVT? |
| Procedural approaches | • Procedural approaches (content related to specific surgical approaches, examination procedures, or other procedures used for patient care) |
| Imaging | • Imaging interpretation |
| Pathology | • Pathology |
| **Sequence** | |
| **Arrangement of subject matter** | How much do you agree or disagree with the following statements about the organization of the content taught in your curriculum? |
| Anatomical | • Subject matter is arranged regionally (i.e. pelvis, abdomen, head & neck, etc.)<br>• Subject matter is arranged systemically (i.e. respiratory, cardiovascular, reproductive, etc.) |
| Procedural | • Subject matter is arranged according to specific procedures. |
| Progressive learning | • Subject matter is arranged progressively, with simple topics covered first followed by increasingly complex topics. |
| **Arrangement of learning experiences** | How much do you agree or disagree with the following statements about 3DVT use in your curriculum? |

| | |
|---|---|
| Early use of 3DVT | • 3DVT is primarily used early in the learning process (e.g. for introducing topics or allowing students to preview material prior to other types of sessions). |
| Later use of 3DVT | • 3DVT is primarily used later in the learning process after students have built a base understanding of material using other methods. |
| Spread out use of 3DVT | • 3DVT use is spread across learning experiences. |
| **Processes** | |
| **Instructor-centered** | About how often do you incorporate 3DVT into the following instructional methods? |
| Lecture | • Lectures |
| Demonstration | • Demonstrations |
| Questioning | • In-class questions |
| **Interactive** | |
| Discussion | • Discussions |
| Group projects | • Group projects |
| Peer-teaching | • Peer-teaching |
| **Experiential learning** | |
| Clinical | • Clinical experiences |
| Simulations | • Simulations |
| Laboratory | • Laboratories |
| **Individualized** | |
| Modularized instruction | • Self-study modules |
| **Evaluation** | |
| **Summative assessment** | About how often do you use the following methods for integrating 3DVT into summative assessments (grades, end of unit evaluations, measurements of proficiency, etc.)? |
| 3D screenshots | • Using screenshots of 3D images to create assessment items |
| Simulation examination | • Using 3D simulation for summative assessment |
| **Formative assessment** | About how often do you use the following methods for integrating 3DVT into formative student assessments (providing feedback for improvement, on-going evaluations, monitoring progress, etc.)? |
| Simulation | • Using 3D simulation for formative assessment |

| | |
|---|---|
| Self-quizzing | • Providing students with 3D technology that includes a self-quiz function |
| In-activity questions | • Incorporating questions into activities involving 3DVT use |
| **Limitations of Use in Assessment** | |
| Difficulty in assessment | In your experience, how difficult are the following activities related to the assessment of student learning?<br>• Designing effective assessment of student learning<br>• Incorporating 3DVT into assessment tools |
| Use of other methods | About how often do you use methods other than 3DVT for the assessment of student learning? |

# CHAPTER 5: DISCUSSION

This study provides a comprehensive examination of how faculty use 3DVT for anatomy education in the medical curriculum. This use is related to components of the curriculum that faculty must consider when deciding how to integrate 3DVT, such as how the resource should be used, in what type of learning experience it should be used, what topics should be taught and when, what students should learn from its use, and how this learning should be assessed. While several of the types of 3DVT use described in this study have been discussed in the literature, this study advances the literature by situating 3DVT use within a definitional framework to provide important contextual details related to the individual elements of the medical curriculum.

Faculty use 3DVT as an instructional resource for supplementing teaching when other methods are seen as lacking, improving the way students can view complex anatomy, customizing learning experiences, and trying to enhance learning. They teach a wide range of systemic, regional, and clinical anatomy topics in an effort to help students build a foundational understanding of anatomy, gain clinical knowledge and skills, and develop the personal traits needed to work effectively as a physician. Some faculty feel that 3DVT use should occur early in student learning, while others feel later use is important to allow for students to learn key concepts first. Faculty incorporate 3DVT into a variety of learning experiences. These experiences may be instructor-centered or involve more interactive approaches, while other experiences incorporate experiential or individualized learning. Finally, while some faculty utilize 3DVT for formative or summative assessment, designing adequate evaluation of student learning poses a challenge for many.

This study also explored how the use of 3DVT compared across the preclinical, clinical, and postgraduate levels of medical education. Finally, the resulting themes of 3DVT use were used to develop a questionnaire grounded in participant perspectives, which will allow for future quantitative analysis of 3DVT use. This chapter describes the utility of the academic plan framework which guided this study, and then presents a discussion of the resulting themes, including the implications of these findings. Limitations and future directions of the study will also be considered.

**Utility of the Theoretical Framework**

To ensure the research encompassed important aspects of a curriculum Lattuca and Stark's (2011) academic plan model was used as a guiding framework for this study. This model provided a definitional framework of a curriculum that effectively guided the formation of research questions, informed the creation of an interview guide, and provided an organizational scheme for the thematic analysis. The use of a broadly applicable model allowed for its application to the specific aspects of anatomy education, while also allowing comparison across the different levels of medical education.  Additionally, use of a model that focuses on the decision-making process of a curriculum means the resulting framework of 3DVT use can be readily implemented to inform meaningful discussions of its integration and identify new areas for the continuing assessment of its effectiveness. The discussion of the implications of this research in the following sections highlights the utility of this model in creating meaningful results which focus attention on key educational considerations.

## Discussion of Themes

Existing literature includes an abundance of authors who have described the creation, implementation, and/or assessment of various types of 3DVT in medical education. While many of them have described uses of 3DVT similar to the themes found in this study, these accounts are often anecdotal, ill-defined, or do not represent authentic use in medical curricula. This study utilized a cross-sectional approach to explore 3DVT use across disciplines, programs, and levels of the curriculum. To this researcher's knowledge this study is the first to examine faculty use of 3DVT within a definitional framework, in order to provide a comprehensive description of its use relative to multiple elements of a curriculum. Published descriptions of 3DVT use are often missing details related to these curricular elements which are important for a thorough understanding and may have important impacts on the effectiveness of 3DVT as a teaching tool. Additionally, studies assessing the effectiveness of 3DVT are often done in research only settings, outside of use in any curriculum.

### *Use as an Instructional Resource*

Faculty use 3DVT as an instructional resource in a broad number of ways, with many of these uses described in the literature by those who have developed and/or assessed these technologies. Participant descriptions of 3DVT use as a teaching tool from this study largely align with what authors commonly contend are benefits of 3DVT.

However, this study offers additional context by providing genuine accounts of use in various medical curricula. Additionally, the themes for this curricular element provide additional framing by organizing faculty use into four broad areas that describe how faculty hope to use 3DVT as a resource to fill deficiencies of other tools, improve visualization, and customize or enhance learning experiences.

One-way faculty use 3DVT for trying to fill a deficiency is by implementing it as a tool for supplementing or replacing cadaveric or animal labs. Articles in the literature commonly comment on the potential for 3DVT to be used for supplementing labs, citing costs (Nicholson et al., 2006; Hu et al., 2010; Yeung et al., 2012), decreasing availability of donors (Balogh et al., 2004; Arora et al., 2012; Nguyen et al., 2012), issues with longevity of specimens (Dobson et al., 2003; Chen et al., 2017), and ethical concerns (Yeom et al., 2017) as reasons for the decreasing amount of time spent in dissection labs. Indeed, this study found that faculty at both the preclinical and postgraduate level are using 3DVT for these reasons. The description by one participant provides additional context demonstrating how the negative perceptions of administration regarding anatomy labs can act as the driving force behind a decision to eliminate cadaver labs altogether.

Faculty may turn to 3DVT when they feel other instructional resources cannot provide adequate visualization of certain regions or anatomical complexities. Preclinical and postgraduate faculty in this study described limitations of certain methods that were similar to those expressed in the literature, including the unrealistic nature of embalmed specimens (Aziz et al., 2002), difficulty viewing small or complex structures in donors (Nicholson et al., 2006; Tan et al., 2012; Chen et al., 2017; O'Rourke et al., 2020), and the narrow viewpoints offered by laparoscopic cameras (Balogh et al., 2004). Additionally, participants described how they feel plastic models poorly represent layers, and thus use 3DVT for helping students gain a better appreciation of the three-dimensionality of layered structures than they may have gotten using plastic models.

Faculty use 3DVT to increase student access to learning resources when and where other methods may not be readily available, and previous literature has discussed the benefits of the portability and flexibility of access offered by 3DVT (Nieder et al., 2000; Lewis et al., 2014). The findings of this study indicate preclinical faculty are interested in not only providing students with a tool for at-home study, but also want students to be able to take it with them as they move into clerkships. This is in line with the discussion by Adamczyk et al. (2009) who describe the potential for the use of multimedia teaching tools to provide anatomy education during clinical training when basic science faculty availability may be limited. Postgraduate faculty, from this study and the literature, also look to 3DVT to provide standardized access to examination or operative procedures when access to patients or time in the operating room is limited (Corton et al., 2003; Balogh et al., 2004).

Faced with a reduced number of hours for teaching and increasing pressures to improve resident training, faculty look to 3DVT to improve efficiency of teaching and learning. In their assessment of a stereoscopic vascular model, Cui et al. (2017) point out the need to increase the efficiency of student learning in the face of reduced contact hours. Yet this study found that preclinical participants focused more on how they use

3DVT in an effort to run labs more efficiently. On the other hand, at the postgraduate level, faculty in this study described using 3DVT with the hope that it can increase the efficiency of student learning. This is in line with Hu et al. (2010) and Arora et al. (2012), who describe a 3D model of the larynx and a virtual reality temporal bone simulator, respectively, as potential tools for increasing the efficiency of teaching surgical anatomy and surgical procedures.

A final way faculty look to fill the deficiency of other teaching methods is by using 3DVT to create low risk training opportunities. In their discussion of the validation of a temporal bone dissection simulator, Arora et al. (2012) point to the benefit of using virtual reality to reduce training risks and improve efficiency of skill acquisition, though they do not assess the ability of the technology to do so. Similarly, some of the postgraduate participants in this study described using simulations with the hope that surgical residents could gain familiarity with the tools and settings of the operating room prior to performing actual procedures where patients could be at risk of injury.

Faculty use multiple functions offered by 3DVT for trying to improve the ways students can view complex areas of anatomy. Similar to the perspectives of participants in this study, a large number of articles have been published with authors citing features such as rotation, animation, manipulation of visualizations, and additional 3D perspective, which they feel are beneficial for student learning (Friedl et al., 2002; Trelease and Rosset, 2008; Hoyek et al., 2014). For example, Nguyen et al. (2012) describe how animations provide dynamic visualizations which showcase the change of structures with respect to time, and further explain their perspective that “the multiple views provided by rotating an object more accurately depicts the visuospatial properties of anatomical structures” (p.99).

In addition to descriptive papers, multiple studies have looked to assess if these factors impact learning. Beermann et al. (2010) found that 3D models improved student identification of surgical liver anatomy, but that coloring the different vessels of the 3D model did not further improve performance. Balogh et al. (2004) created stereoscopic videos of neurosurgical procedures in an attempt to address the limited depth of field inherent in traditional intraoperative videos, but only provided anecdotal accounts of residents and fellows reporting satisfaction and learning. The current study adds additional context to these reports by providing details on how faculty use these features, such as participants who described using structure isolation tools to demonstrate vessel or nerve pathways, the transparency function for helping students visualize relationships, and rotation of visualizations for demonstrating pathways or structure relationships.

Another theme of 3DVT use as an instructional resource described by this study was customization of learning experiences. While published literature does not explicitly refer to the use of 3DVT for customizing learning experiences, some authors do describe the use, or the potential for use, of 3DVT to tailor learning experiences by creating focused content (Lo et al., 2020), demonstrating pathologies (Balogh et al., 2004; Brown et al., 2012; Eid et al., 2017), or integrating multiple topics (Silén et al., 2008). Weber et al. (2012), for example, held student focus groups related to virtual anatomy labs and report on the importance of focusing content, stating:

> Indeed, students stressed that economy of time was of utmost importance to them and they were not compelled to try any innovations that were not assured to be of great use for the material being studied. Thus it is essential to tailor online learning resources to the curriculum of a particular medical school rather than rely on tools, commercial or otherwise, designed with a broader focus.

Similarly, participants in this dissertation study described focusing content by creating specific lesson plans walking students through content, utilizing unique sequencing of activities related to specific operations, or labeling only those structures which were relevant to a lesson.

One study that looked at using 3DVT for the demonstration of pathologies was conducted by Brown et al. (2012), who reported that students rated 3D models of aortic aneurisms as helpful in their learning of anatomy and pathology. While their study included only one trial of a single tutorial and did not represent a true integration of use in the curriculum, students did indicate that they felt additional stereoscopic tutorials covering other pathologies would provide additional benefit to the curriculum (Brown et al., 2012). Faculty participants in this study also used 3DVT for demonstrating pathologies, and further described how they obtained images of pathologies by using preexisting images available with the technology, loading patient specific scans, or custom programing specific pathologies.

Faculty participants in this study explicitly described using 3DVT for the purpose of horizontal and/or vertical integration, indicating they used it for adding clinical, histological, and imaging content into activities with 3D models. While those describing 3DVT use in the literature do not directly describe using 3DVT for integration, they do provide examples of clinical information which is presented using 3D models. Trelease and Rosset (2008) describe the use of diagnostic imaging for creating volumetric models to involve students in learning anatomy in clinically relevant contexts; however, their article only describes the creation of the models, not the use of those models in a curriculum. Existing literature lacks descriptions of the type of horizontal integration of foundational science topics like what was described by the participant in the current study, who included histological content on 3D tables in the lab.

Faculty often describe using 3DVT because they feel it is a resource that has the potential to enhance learning experiences, and participants in this study described linking visualizations to course elements as one way they try to enhance learning experiences for students. In their review of anatomy software available for tablets Lewis et al. (2014) report that "[t]hey often contain additional content including clinical correlations and a range of media from instructional videos to interactive quiz functions" (p. 313). Additionally, in a study examining student learning preferences Adamczyk et al. (2009) propose that one benefit of technology is the potential for deeper interlinking of materials. Similarly, others have described creating 3D visualizations that contain links to recorded narrations (Trelease and Rosset, 2008), video clips (Hampton and Sung, 2010), or additional clinical information such as risk factors, screening protocols, and treatments (Brown et al., 2012).

Utilizing 3DVT as a resource to engage students is another way faculty hope to enhance learning experiences. In his discussion of anatomy education, Turney (2007) expresses a need for promotion of instructional resources or methods that stimulate interest in anatomy and stresses that anatomy should welcome an IT revolution. A survey by Cui et al. (2017) found that students rated 3D vascular models of the head and neck as interesting, and the vast majority indicated the models engaged them in learning the material. The results of this dissertation study add additional context related to how faculty use 3DVT to engage students, with faculty participants describing how they utilized student interest in novel technologies and included interaction with technology during lecture sessions in an effort to promote engagement. Although faculty may hope student interest in technology is enough to promote engagement, Weber et al. (2012) found that students indicated an "eDemonstrator's" presence in a virtual anatomy lab was motivating and engaging, which suggests that an instructor may be needed to encourage student engagement with online material.

Finally, faculty feel that 3DVT can be used to enhance learning by providing repetition and new methods for team training. There is a paucity of published information related to use of 3DVT for providing repetition and team training. While Lelardeux et al. (2016) discuss the use of a 3D virtual operating room for evaluating teamwork efficiency among student trainees, the module was used for teaching risk management, not anatomy. And while Abid et al. (2010) mention repetition as one benefit of 3DVT, their comparison of 3D to traditional chalk teaching did not allow for students to repeat the 3D modules. While information about the use of 3DVT for repetition and team training is scarce, this study describes how faculty use 3DVT because it allows students to repeat modules until necessary knowledge is obtained and provides students a chance to practice clinical exam skills. Further, this study highlights how postgraduate faculty use 3DVT to provide interprofessional training and to help residents develop teamwork skills needed in the operating room.

### Implications: Use as an Instructional Resource in the Medical Curriculum

This study demonstrates that faculty choose 3DVT as an instructional resource for a wide range of reasons, which suggests there may be opportunities for educators to consider 3DVT from a broader perspective of potential use. Those responsible for planning the curriculum and designing anatomy education should consider how they can best leverage the abilities of the technology to address needs beyond just improvement of learning. They must consider if 3DVT can help achieve the goals of a curriculum and examine how it could be used to augment other teaching resources, provide flexibility in curricular design and delivery, facilitate integration, and enhance learning experiences.

3DVT may provide the opportunity to augment other resources and help balance out deficiencies or limitations of these other resources. For example educators may want to consider using 3DVT if other methods are not available, don't provide the necessary views of certain anatomy, aren't easy for students to access in flexible ways, take too much time to use, or create unnecessary risks for patients. Anatomists seem to agree that there is likely no single, best method for teaching anatomy, and contend that modern teaching should utilize a combination of methods in ways that maximize learning (Turney, 2007; Ghosh, 2017). Additionally, institutions who have successfully combined resources should report on their experiences to help inform best practices for utilizing 3DVT to augment other methods.

Educators may also want to consider the utilization of 3DVT as a flexible and customizable teaching resource. It is possible that the benefit of such flexibility is undervalued in its ability to tailor lessons to the need of a class. For example, in institutions utilizing systems-based blocks 3DVT could be used to narrow the focus of content presented to just the system of interest. Similarly, 3DVT could be used to tie anatomy into case-based learning by customizing the content based on structures and pathologies relevant to the case being studied. Additionally, Adamczyk et al. (2009) point to potential benefits of giving students the option to pick the structure of learning materials to match their individual cognitive styles. For example, 3DVT may provide a way for instructors to let students choose a breadth first or depth first approach to learning.

Use of 3DVT for customization can also provide a tool for adding clinical content, and administrators looking to support an integrated curriculum should consider how 3DVT can be utilized as a tool for supporting and facilitating the addition of clinical content into anatomy education. There has already been a call for the use of 3DVT to further integration of clinical content, and a number of authors have described technologies which provide clinical information through patient vignettes, visualization of patient scans, or 3D multimedia demonstrating treatments (Friedl et al., 2002; Trelease and Rosset, 2008; Brown et al., 2012; Yammine and Violato, 2015; Eid et al., 2017). This study provides evidence that faculty are already using 3DVT for integration, and further demonstrates how the ability to customize learning materials, demonstrate pathologies, and link visualizations to additional clinical information allows teaching materials to connect normal anatomy to a wide range of case studies.

Finally, descriptions of 3DVT use by participants in this study suggest that educators should consider where use of 3DVT as a teaching tool may provide opportunities to enhance learning by providing repetition, engagement, and team training. These tools could be considered in situations where repetition may aid learning, such as providing practice through simulation for procedural skills development or use of repeatable virtual dissection to help students build more complex mental models. Additionally, educators looking to increase student engagement could explore the opportunity to use 3DVT to capitalize on student interest in novel technologies. Finally, virtual environments could be considered by those who are looking to provide unique opportunities for teaching content while helping learners develop interpersonal skills. While educators can consider 3DVT use in variety of ways, they must carefully consider the evidence, internal or published, regarding the effectiveness of 3DVT for enhancing learning in these ways.

**Implications: Assessment of Use as an Instructional Resource**

When making decisions about how best to incorporate 3DVT into the curriculum, educators need to consider the evidence related to its effectiveness. Current research examining the effectiveness of 3DVT for anatomy education relies heavily on evaluation of student perceptions and knowledge outcomes such as factual or spatial understanding (Yammine and Violato, 2015; Hackett and Proctor, 2016). Yet, this study suggests that 3DVT is being used in a broader scope as a resource than just to improve understanding. Therefore, continuing assessment of the effectiveness of 3DVT as a teaching tool should encompass the many aspects of 3DVT use described in this study.

Faculty are not just using these tools because they feel like they are superior to other methods of teaching, but because they fill a need by being able to supplement other tools in a way that helps balance deficiencies of other resources. Therefore, assessment of the effectiveness of 3DVT should examine more than whether or not 3DVT produces better knowledge gains than other resources. For example, one of the only studies comparing 3DVT to dissection labs was done by Hisley et al. (2008), who compared digital dissection to actual dissection used in a seminar for students who performed well in anatomy. Their findings suggest that digital dissection may be a viable alternative to dissection. For instructors faced with no access to cadaver labs, evidence that 3DVT is equivalent to dissection, or other available methods such as text with 2D images or lectures, may be sufficient to justify use of 3DVT for teaching.

Additionally, many of the studies evaluating 3DVT are done in controlled settings, where students access materials from a specific location for a predetermined amount of time. These types of study designs do not allow for examination of how ease of access to different resources affects student learning. Assessment of 3DVT as a teaching tool needs to include studies which examine how successful it is in filling the types of deficiencies described by participants. That is, can it adequately supplement teaching in wet labs? Does it allow for visualization of certain concepts or structures not possible with other methods? Does it provide students increased opportunities for learning in certain environments? Can it improve the efficiency of learning sessions?

And, does it provide adequate learning opportunities while lowering the risk to patients?

Similarly, if faculty are using 3DVT because they feel certain features aid students' ability to adequately visualize structures and structural relationships, then the ability of 3DVT to achieve this must be assessed. In their meta-analysis, Yammine and Violato (2015) describe how controls to rotate, invert, and move around images provide students with multiple viewpoints and angles for viewing spatial relationships of structures. Yet, they did not examine the effect of these functionalities in their meta-analysis, such as by using a subgroup analysis to compare software that allows for rotation to those that do not, which might have provided insight into the impact this feature has on student learning. Similarly, while a number of articles report creating 3D visualizations that provide image modification, rotation, animations, or stereoscopic views, many studies do not analyze the effectiveness of these features for teaching, or if they do, the assessment fails to properly isolate these specific features to test their impact (Friedl et al., 2002; Balogh et al., 2004; Trelease and Rosset, 2008; Brown et al., 2012).

Additionally, faculty use of these 3DVT features is not just about improving learning, faculty use them with the hope that it will allow students to visualize complex anatomy more easily. While numerous studies report positive student feedback related to 3DVT use for anatomy education, this study highlights the need for more information regarding how students feel specific features impact their ability to visualize anatomy. Finally, observational studies may be useful for providing additional insight into how students use these tools for viewing and learning anatomy and anatomical spatial relationships.

Further assessment is also needed to examine the ability of 3DVT to aid in the customization learning experiences and provide insight into how focusing content, demonstrating pathologies, and integrating content impacts student learning. For example, faculty use 3DVT for focusing content, but if they are investing a significant amount of time customizing sessions then more information is needed about whether this reduction of other information aids students learning. Also, while integration is a current focus of medical educators, and some evidence suggests positive outcomes related to integration (Dubois and Franson, 2009; Bandiera et al., 2018), there is not sufficient evidence related to the impact of using 3DVT for integration. More information is needed about how the use of 3DVT actually impacts the amount of integration faculty can achieve, and whether this integration impacts students' ability for holistic thinking, long term retention of material, or ability to apply anatomical knowledge in clinical problem solving. Finally, further assessment should explore the impact of using 3DVT for demonstrating pathologies, particularly how demonstration of abnormal anatomy aids learning and how demonstration of pathologies during resident training impacts patient care and surgical outcomes.

While faculty use 3DVT with the hope of enhancing learning experiences, its continued use for these reasons should be based on evidence that 3DVT can indeed positively impact student learning. While faculty hope to capitalize on the ability to link visualizations with additional content, there is a lack of literature examining the impact of this specific utilization of the technology. For example, Brown et al. (2012) describe creating an interactive 3D tutorial with links to additional clinical information, but they did not assess learning outcomes and the feedback they collected from students did not include details related to the perceived usefulness of the links. Similarly, more information is needed on how repetition of 3DVT use adds to learning. For example, when dissections cannot be repeated, what is the impact on learning if 3DVT is used after labs as a tool which can be reused for review? Also, more evidence is needed regarding the utility of 3DVT for enhancing team training. Furthermore, the observations reported by Hopkins et al. (2011) that student groups using 3D teaching materials in lab tended to split up into smaller discrete groups suggests more data is needed on the type of social interactions created when learning activities include 3DVT.

Finally, while faculty hope to utilize student interest in technology to enhance learning, student engagement is not measured in studies assessing 3DVT as a teaching tool. In their study assessing stereoscopic liver models, Hu et al. (2010) reported that students rated the 3D models as more fun. This finding is not unique, and in fact Hackett and Proctor (2016) and Yammine and Violato (2015) both describe a large number of studies demonstrating positive student perceptions of 3DVT and high student interest in continued future use. However, students' perceptions that technology is interesting, or fun, does not necessarily indicate engagement or improved learning. Observational studies of the classroom may be needed to adequately gauge the level of authentic engagement of students during 3DVT use.

*Purposes*

Faculty have a variety of intended learning outcomes they hope students will achieve from the use of 3DVT, and many of the knowledge, attitudes, and skills they hope students will acquire are described in the literature by those who have developed and/or assessed these technologies. However, this study adds to the literature by providing genuine accounts of 3DVT use in various medical curricula and adds context for understanding the specific ways faculty use 3DVT to try to achieve these goals. Additionally, the organization of themes for this curricular element provide a framework for considering the purposes of 3DVT use, and structure intended learning outcomes according to foundational knowledge and skills, clinical knowledge and skills, and preparing students for work as physicians.

Faculty hope that students will gain important fundamental understanding of anatomy from the curriculum and describe a multitude of ways they use 3DVT to try to help students achieve this foundational knowledge. Faculty participants and authors alike have commented on the potential for 3DVT to help students learn to identify structures, understand structure pathways, and describe the organization of the human body (Marsh et al., 2008; Abid et al., 2010; Hu et al., 2010; Ruisoto et al., 2012; Hoyek et al., 2014). Many studies have examined the effect of 3DVT use on factual knowledge outcomes, and Yammine and Violato (2015) included factual knowledge as a component of their meta-analysis which showed mixed results for the efficacy of 3DVT compared to traditional 2D methods. In addition to the understanding provided by the literature, the current study provides detailed examples of the ways faculty use 3DVT for conveying fundamental knowledge, such as by using rotation to demonstrate structure pathways, the ability to link visualizations to provide additional structure information, and increased accessibility to provide an easier method for review.

Another foundational knowledge and skills area faculty discuss as a purpose of the curriculum is that of providing students with an understanding of how form is related to function. Current literature lacks explicit discussion of the use of 3DVT for teaching form and function, and only a few authors describe learning outcomes related to this area. For example, Silén et al. (2008) describe the use of 3D images and films for teaching functional anatomy, and explain how the dynamic nature of movement is not well portrayed using standard textbooks and figures, citing the difficulties students have understanding “the change of muscle force direction due to transition of a flexor into an extensor depending on how the joint is angled” (p. 115). Descriptions by participants in the current study provide a deeper understanding of how faculty use animations and isolation of structures for teaching students about how structure is related to function, or in some cases disfunction.

As could be expected, a number of faculty hope that 3DVT can be used to help students develop a strong 3D understanding of anatomy. Both participants and authors in the literature have discussed at length the need for medical education to help students develop an understanding of the spatial relationships of structures, and build an ability to visualize the three-dimensional shape of structures (Rengier et al., 2009; Beermann et al., 2010; Yeung et al., 2012; Cui et al., 2016; Chen et al., 2017; O'Rourke et al., 2020). Similarly, many studies have examined the effect of 3DVT use on spatial knowledge outcomes, and Yammine and Violato (2015) included spatial knowledge as a component of their meta-analysis which found significantly better spatial knowledge acquisition with 3DVT use compared to traditional 2D methods. Descriptions by faculty in this study add to the literature by offering detailed accounts of how participants use 3DVT for conveying 3D knowledge, such as by using rotation to demonstrate relationships, linking visualizations to content that describe structure relationships, providing repetition to help students build 3D mental models, and using image modification to provide visualizations of layers.

Faculty hope that students will take away a number of different clinical knowledge and skills, and one learning outcome tied to this involves helping students grasp the clinical relevance of the anatomy they are learning. Similar to participants in this study, numerous authors describe the need to demonstrate the relevance and applicably of anatomy, and advocate for the use of 3DVT integrate clinical content and demonstrate pathologies (Abid et al., 2010; Cui et al., 2016; O'Rourke et al., 2020). Rengier et al. (2009) provide an example of integrating anatomy with radiology and describe the use of 3D image post-processing tools to illustrate clinical relevance. Further, descriptions by participants in this study demonstrate how faculty use 3DVT for teaching clinical relevance by linking visualizations to additional clinical content, or using animations containing clinical content.

Another component of clinical knowledge and skills that faculty describe as a learning outcome is students’ ability to recognize and interpret anatomy seen in imaging. Numerous authors have described the potential for 3DVT to be used for teaching imaging interpretation skills (Metzler et al., 2012; Müller-Stich et al., 2013; Eid et al., 2017) and, similar to participants from this study, several refer more specifically to the hope that 3DVT can help with teaching students to interpret cross-sectional images (Donnelly et al., 2009; Cui et al., 2016). In fact, Donnelly et al. (2009) and Rengier et al. (2009) each describe the integration of 3DVT into actual medical curricula for the purpose of teaching imaging interpretation. This study provides additional examples of how preclinical and postgraduate faculty try to help students develop imaging interpretation skills by using 3DVT to link visualizations with imaging content, provide an alternative method of viewing cross-sections, and rotate models for demonstrating where structures might overlap on imaging scans.

Understanding anatomy related to procedures is another part of the clinical knowledge and skills that faculty hope students can take away from medical education and the use of 3DVT. Accounts in the literature are predominantly authors describing a technology with the potential for teaching the anatomy of procedures and, similar to participant descriptions, they discuss surgical and/or clinical examination procedures (Friedl et al., 2002; Keedy et al., 2011; Arora et al., 2012). For example, Hampton and Sung (2010) describe the creation of a teaching module which includes a demonstration of a urogynecological pelvic examination side by side with a 3D model of the relevant pelvic anatomy. Chen et al. (2017) describe creating a 3D model that allows for exploration of a trans-sphenoidal pituitary surgical route, a goal similar to participant descriptions of using 3DVT to teach residents how to access and safely navigate around structures.

Although understanding the anatomy of procedures is an educational purpose already described in the literature, the accounts from this study allow for a deeper understanding of how faculty are using 3DVT within curricula for trying to help students achieve this particular learning outcome. Faculty participants described teaching the anatomy of procedures by using 3DVT to increase accessibility and standardize learning of operative procedures, link visualizations to content detailing steps of procedures, provide an engaging way for learners to interact with procedural anatomy, and create content focused on only the anatomy relevant to the procedure being learned.

The final educational purpose that faculty discuss related to providing students with clinical knowledge and skills involves helping students understand diagnosis and disease management. Several authors in the literature have described 3DVT which could be used for teaching diagnosis and disease management, including Hampton and Sung (2010) who describe using 3D models and animations to demonstrate surgical and nonsurgical management of pelvic organ prolapse. Others have similarly discussed how a 3DVT they describe could be used to teach radiological diagnostic skills (Rengier et al., 2009), signs of and treatment for aortic aneurisms (Brown et al., 2012), and the anatomy necessary for understanding anorectal disease states (Dobson et al., 2003). This study adds additional context by highlighting how one way that faculty incorporate information related to diagnosis and disease management is to use 3DVT for demonstrating pathologies in a way such that students are then responsible for establishing a differential diagnosis.

In addition to foundational and clinical knowledge and skills, faculty hope that the curriculum will help students develop a number of personal attributes which will prepare them for work as a physician. Similar to faculty descriptions in the current study, a number of studies have assessed or described the ability of 3DVT to be used for procedural skill training (Hanna et al., 1998; Roach et al., 2012), most commonly in relation to the use of simulators for surgical skills training (Arora et al., 2012; Willaert et al., 2012; Cho et al., 2013; Vaccaro et al., 2013). Also, similar to the findings of this study, some authors propose one benefit of 3DVT for skills training is its ability to provide repetition and create low-risk training opportunities.

However, much of the previous literature neglects discussion of the use of 3DVT for development of interpersonal skills or self-directed learning. For example, numerous studies describe creating 3D material used for self-study (Donnelly et al., 2009; Yeom et al., 2017; O'Rourke et al., 2020), but none talk about designing 3D materials specifically for the purpose of helping students develop their self-directed learning skills, or interest in lifelong learning. Yet, discussions by participants in this study highlight how faculty are using 3DVT to engage students to stimulate their sense of self-discovery and promote interest in future self-learning. Further, this study highlights how faculty are using 3DVT to provide team training, and to promote development of interpersonal skills such as teamwork, leadership, and communication.

### Implications: Assessment of Learning Outcomes

It is clear from the literature and the findings of this study that the educational goals set by faculty include a wide variety of knowledge, attitudes, and skills that they want students to attain from anatomy education and the use of 3DVT. Educators looking to design learning experiences to meet these types of learning objectives should carefully consider how instructional resources, including 3DVT, can be used most effectively to facilitate student learning. Additionally, as is true in any curriculum, careful and rigorous assessment should be done to determine if students are adequately meeting the intended learning outcomes.

Further, as educators consider the use of 3DVT, they should evaluate the evidence related to the effectiveness of 3DVT for achieving the types of learning outcomes intended for its use. While a great deal of work assessing the effectiveness of 3DVT has been published, current research focuses on a narrow set of outcomes related primarily to spatial and factual knowledge, and the broader set of outcomes described by this study suggests gaps remain. Additionally, the mixed results of current research on 3DVT effectiveness suggest that assessment needs to examine variations in use, which may affect outcomes. This study provides details related to how faculty utilize 3DVT to try to achieve various learning goals, and most studies do not examine the links between these specific types of use and the impact on learning outcomes.

In terms of foundational knowledge and skills, a number of studies have assessed the effectiveness of 3DVT for helping students achieve fundamental and 3D understanding (Hackett and Proctor, 2016). Continuing studies are needed to also assess how individual factors of use (rotation, linking visualizations to additional content, image modification, etc.) impact these types of factual and spatial outcomes. Additionally, while questions related to form and function are likely part of the factual knowledge tested in many studies, there is a lack of research specifically examining how 3DVT impacts students' ability to understand structure function relationships. Further assessment of 3DVT could explore if animations help students learn muscle movements, or if being able to modify images to view isolated muscles adds to students; understanding of actions.

While there are a number of studies assessing 3DVT that examine outcomes related to the clinical knowledge and skills described by this study, there are still gaps which could be further explored. For example, (Abid et al., 2010) reported that students taught embryology with 3D learning modules did not perform any better on clinical implication questions than students taught with chalk drawings. However, it is unlikely that these type of simple recall questions adequately measure a students' true understanding of clinical relevance or their ability to demonstrate the applicability of anatomy. Also, this comparison to chalk drawings does not add to the understanding of how animations, linking visualizations to clinical content, or the ability to demonstrate pathologies influence student understanding of clinical relevance.

Similarly, while some studies have explored 3DVT use for outcomes related to diagnosis and disease management or anatomy of procedures, these outcomes are difficult to measure adequately. For example, Balogh et al. (2004) only reported residents' and fellows' self-perceptions that they had a better understanding of anatomical relationships after viewing 3D operative videos. Additionally, Hampton and Sung (2010) found no significant difference between knowledge and attitude scores of residents randomized to a 3D trainer and the scores of those exposed to traditional teaching. Yet, it is unlikely that self-reported gains of knowledge, or scores on multiple choice exams, can truly capture a person's understanding of diseases and their associated treatment, or adequately assess their ability to safely access and navigate around structures. More rigorous assessment is needed in this area, and this assessment needs to include examination of the details of 3DVT use which affect these clinical knowledge and skills outcomes.

While the ability to accurately interpret anatomy seen in medical imaging is likely easier to assess than knowledge of diagnosis and disease management, there is mixed evidence regarding the effectiveness of 3DVT for this purpose. For example, Metzler et al. (2012) and Müller-Stich et al. (2013) conducted nearly identical studies testing student ability to identify structures of the liver on 2D images and describe the shape of tumors seen in imaging. Yet, Metzler et al. (2012) reported no difference between the 3D and 2D groups, while Müller-Stich et al. (2013) found that students in the 3D group outperformed the 2D group. Closer examination shows that the 3D images in the study conducted by Müller-Stich et al. (2013) were stereoscopic, while those in the other study were monoscopic. This suggests that the additional 3D perspective provided by the stereoscopic images may provide an additional advantage for students learning to interpret liver imaging. Providing 3D perspective is just one of the ways faculty describe using 3DVT for teaching imaging, and additional research is needed to examine the relationship between these different uses and student learning.

Similarly, there has been mixed evidence published related to the efficacy of 3DVT for procedural skills training. For example, Roach et al. (2012) reported that 3D video learning modules are no more effective than 2D videos in contributing to surgical skill acquisition. However, others have reported improvements in surgical skills after use of virtual reality simulation trainers (Willaert et al., 2012; Cho et al., 2013; Vaccaro et al., 2013). Again, the specific attributes of 3DVT use should be examined to understand how variations in use of the technology contribute to their success or failure as a tool for skills training.

Finally, there is a notable absence of studies examining the impact of 3DVT use on interpersonal and self-directed learning skills. Even more concerning is the report by Hopkins et al. (2011) that students using 3D computer resources in lab were more likely to split into smaller groups than those working with prosections, and were likely to abandon the 3D resources altogether just prior to an exam. This points to the importance of more research aimed at understanding how use of 3DVT impacts these types of social and professional development outcomes, and how variations in the ways it is used affects outcomes.

*Content*

The content faculty teach using 3DVT covers a wide range of topics, all of which are areas typically associated with anatomy education in the medical curriculum. The literature describing and assessing the use of 3DVT includes discussion of the typical content areas associated with anatomy, and the subject areas identified by this study confirms this variety is also taught using 3DVT in medical education settings. This study also offers additional context by describing the types of knowledge, attitudes, and skills faculty hope to convey by covering specific topics. The themes for this curricular element provide additional framing by organizing content into three common divisions of anatomy: systemic, regional, and clinical.

Preclinical and postgraduate faculty in this study described using 3DVT for teaching systemic content similar to what has been described in the literature, including content from the cardiovascular (Friedl et al., 2002; Silén et al., 2008; Cui et al., 2016), nervous (Estevez et al., 2010; Yeung et al., 2012), muscular (Hoyek et al., 2014), skeletal (Nieder et al., 2000; Trelease and Rosset, 2008), and respiratory systems (Hisley et al., 2008; Yeom et al., 2017). While studies in the literature have also described using 3DVT to cover content related to the gastrointestinal system, such as hepatobiliary anatomy (Beermann et al., 2010; Keedy et al., 2011) and peritoneal embryology (Abid et al., 2010), no participants in this study explicitly mentioned content in this area. This is likely because participants were not asked to exhaustively list content covered, and instead highlighted key examples. Systems not overtly described by participants in this study or authors in the literature include the lymphatic, endocrine, integumentary, and reproductive systems. Finally, this study highlights how faculty teach systemic anatomy content for conveying, most commonly, fundamental, 3D, and procedural anatomical understanding.

Regional anatomy content taught using 3DVT also appears to be similarly described in the literature and by participants in this study, including anatomy of the pelvis (Dobson et al., 2003; Hampton and Sung, 2010), trunk (Nguyen et al., 2012), head and neck (Nicholson et al., 2006; Trelease and Rosset, 2008; Hopkins et al., 2011), and extremities (Hoyek et al., 2014). Articles discussing use of 3DVT for teaching content of the abdomen are limited primarily to the liver, while participants in this study described multiple areas of abdominal anatomy taught. Additionally, this study highlights how faculty teach regional anatomy content for the purpose of conveying fundamental, 3D, and procedural anatomical understanding, as well as imaging interpretation skills.

Finally, faculty use 3DVT for teaching anatomy content in the context of clinical settings. Postgraduate participants in this study and authors in the literature have both described the ability to use 3DVT for teaching specific procedural approaches, both for describing the anatomy and helping learners practice procedural skills (Friedl et al., 2002; Balogh et al., 2004; Beermann et al., 2010; Arora et al., 2012; Cho et al., 2013; Lo et al., 2020). However, these descriptions in the literature are proposed uses for 3DVT or assessments in research settings, not use in an actual curriculum. Additionally, participants and authors alike have described the use of 3DVT for teaching content related to medical imaging (Mastrangelo et al., 2003; Donnelly et al., 2009; Rengier et al., 2009; Ruisoto et al., 2012) and pathology (Friedl et al., 2002; Hampton and Sung, 2010; Brown et al., 2012; Cui et al., 2016).

**Implications: Selection and Assessment of Content Taught**

This study shows a wide variety of topics that educators could consider teaching using 3DVT. Educators looking to use 3DVT for anatomy education should carefully consider what content is taught best using 3DVT, and what knowledge, skills, and attitudes the content is intended to convey. One of the participants in this study utilized virtual labs covering ophthalmology eye exams to provide students with opportunities to practice the procedural skills associated with eye exams, learn the anatomy underlying these procedures, and apply anatomical knowledge to identifying underlying pathologies. This example demonstrates that thoughtful selection of content taught using 3DVT can address several educational goals at once.

Because this study demonstrates how faculty use 3DVT to cover a wide range of topics, the assessment of 3DVT as a teaching tool should also encompass this variety. When designing and describing assessment studies researchers should consider what content they are testing, and work to include a variety of topics to explore how content plays a role in student learning using 3DVT. While studies assessing the effectiveness of 3DVT cover a variety of content areas, some questions remain. For example, are some topics better taught using 3DVT? Furthermore, what knowledge, skills, and attitudes do students take away from sessions covering different content areas?

*Sequence*

When implementing 3DVT, faculty make important decisions about the arrangement of the content taught and the sequencing of student interactions with 3DVT. Articles describing or assessing the use of 3DVT sometimes include discussion surrounding the arrangement of the subject matter or learning experiences, but often the accounts are incomplete or are not included because the use is in isolated research settings. This study adds to the understanding of how faculty sequence 3DVT use by offering real examples of sequencing in a curriculum and highlighting how faculty think about using sequence to achieve desired outcomes. Additionally, the themes for this curricular element provide framing by organizing the sequencing of subject matter and learning experiences into categories of arrangement.

Faculty arrange subject matter according to anatomical, procedural, or progressive learning organizational schemas. As would be expected, preclinical faculty participants described organizing material based on systemic or regional anatomical divisions. Postgraduate participants, on the other hand, often described arranging content based on specialty-specific procedures. Similarly, Chen et al. (2017) described creating a 3D model of the paranasal sinuses which was organized according to the surgical route used in trans-sphenoidal pituitary surgery. In addition to procedural arrangement, postgraduate participants also described sequencing content in ways that allow for progressive learning. While the use of 3DVT for progressive learning has not been well discussed in the literature, Arora et al. (2012) do express the potential of a temporal bone simulator to provide routine training for novice groups, and case-specific training for expert groups. This study provides further insight into how faculty hope to allow for incremental development of skills by presenting simple topics first, followed by increasingly complex ones.

Faculty arrangement of learning experiences is divided between those who use 3DVT early on to introduce concepts and those that use it later after students have built a base of understanding. While participants in this study described early use of 3DVT, there are relatively few examples in the literature. One such example is Abid et al. (2010) , whose study design included using 3D animations for introducing students to peritoneal embryogenesis for the first time. This study highlights how faculty use 3DVT for allowing students to preview content prior to other sessions and provides an example of one who hoped early use of 3DVT would promote increased student adoption of the technology.

Examples of later use of 3DVT are much more common in the literature, though these are typically experimental designs where students have already taken anatomy (Hisley et al., 2008), are given a lecture prior to use of the 3DVT (Metzler et al., 2012; O'Rourke et al., 2020), or are required to complete a tutorial and pass a quiz before accessing the 3D material (Nicholson et al., 2006). Additionally, Aziz et al. (2002) describe the potential for the use of 3DVT after dissection labs, so that students first get the benefits of learning anatomy on a donor, and then study cross-sections using 3D models for reviewing and learning imaging. Similarly, participant descriptions in the current study show that faculty who arrange learning experiences to include later use of 3DVT hope this will allow students to develop a base understanding first, so that they are prepared for more interactive exercises that require application of their knowledge.

Faculty can also choose to spread out integration so that 3DVT is used both earlier and later in the learning process, though this arrangement is less commonly described. Most studies assessing the effectiveness of 3DVT are done at a single time point and cannot examine a more spread out arrangement of use. However, an article by Silén et al. (2008) provides one example of spread out use, where they describe using 3DVT at multiple time points during the cardiovascular block. They explain how students are exposed to various 3D imaging modalities through introductory clinical scenarios, functional anatomy lectures, virtual reality demonstrations, and self-study materials

(Silén et al., 2008). Similarly, participants in this study described having students use 3DVT before lab for previewing material, during lab for guidance, and after lab for review. Additionally, one participant commented on how the use of 3DVT allows them to make material available to students at variable times, whenever is appropriate for the individual's level of training.

**Implications: Designing and Assessing Sequence**

Educators considering the use of 3DVT must think about how best to arrange subject matter and learning experiences to create optimum benefits for students. Although it is common for anatomy faculty to organize content according to systemic or regional anatomical divisions, this study demonstrates how content presented with 3DVT can also be arranged according to progressive learning principles, or specific procedural approaches. The ability to customize the content presented with 3DVT may provide faculty more flexibility in thinking about the sequence of a curriculum. For example, while it might be difficult to rearrange the regionally organized content of a textbook, faculty using 3DVT can think about unique ways to arrange material, such as by clinical case. Further, educators looking to provide students with progressive learning could consider if 3DVT can be used to achieve this, for example by presenting normal anatomy first and then adding in examples of abnormal anatomy.

While there are examples of faculty arranging learning experiences for earlier, later, or spread out use of 3DVT, educators responsible for curricular design should consider the evidence related to ideal timing of 3DVT use. For example, some authors have suggested that when first learning new content, novice students may be overwhelmed by the additional information provided by 3D models, leading to cognitive overload (Hu et al., 2010; Yeom et al., 2017). One study which seems to support this idea was conducted by Marsh et al. (2008), who reported that "students who used a [3D] module performed better than those given only traditional resources if they used the module *after* they were already somewhat familiar with the material" (p. 252). If this is the case, then later use of 3DVT might be advantageous so that students can first build a base understanding.

However, there is also some evidence that the cognitive load barrier faced by students may vary depending on their level of training and experience with the 3DVT modality. For example, Hampton and Sung (2010) only found significantly higher knowledge scores of first year residents randomized to a 3D trainer but not more senior residents. This may suggest that the foundational knowledge residents possess is sufficient to allow success in the early use of 3DVT. Further, Yeom et al. (2017) found that students who had prior experience with a similar type of 3D interface performed better on identification of structures. It is possible that familiarity with the modality of the technology used helps reduce the cognitive load experienced by these students.

It may be that the sequencing of experiences needs to be different for preclinical and postgraduate learners, where in preclinical curricula later use allows for a foundation of knowledge to be built and in postgraduate curricula early use allows them to revisit information before they progress to specialized cases and skills which are beyond the capabilities of the technology. Additionally, faculty implementing 3DVT in early learning experiences should consider how they can help students overcome the amount of information to be processed, such as by giving technical training and sufficient time for familiarization with the software. Additionally, thoughtful longitudinal integration of 3DVT throughout the curriculum may provide an ideal scenario, where students are given ample time to become familiar with the technology, so they then could use it for preview or reviewing material as needed.

The need for consideration of sequencing 3DVT use has important implications for the assessment of 3DVT as well. Evidence is needed regarding when 3DVT use is most effective, yet most studies do not explicitly examine the timing of 3DVT use. Further, the short time frame used in many studies may not be sufficient for learners to become accustomed with the technology, and this may be one reason why some studies do not find 3DVT to be any more effective than other methods. This study highlights additional questions which need to be examined. For example, does earlier use of 3DVT lead to increased adoption of technology? How effective is 3DVT for preparing students for lab? Finally, more assessment needs to happen in the context of actual use of 3DVT in the medical curriculum.

*Instructional Processes*

Faculty incorporate 3DVT into many different types of instructional processes. While 3DVT use in various types of learning activities has been described in the literature by those who have developed and/or assessed these technologies, these accounts are anecdotal and this study adds to the understanding by providing contextual information on how faculty actual incorporate 3DVT into these processes within medical curricula. Additionally, this study provides framing by using Weston and

Craton's (1986) four categories of instructional methods to define faculty use of 3DVT in instructor-centered, interactive, experiential, and individualized learning processes.

Faculty incorporate 3DVT into instructor-centered methods, such as lecture, demonstrations, or questioning, where the teacher is primarily responsible for conveying information. Several authors have expressed the potential for described technologies to be used in either lectures or demonstrations (Dobson et al., 2003; Trelease and Rosset, 2008), while others have described study designs which include 3DVT use in these settings (Beermann et al., 2010; Hoyek et al., 2014; Cui et al., 2017). Similar to participant descriptions of demonstrations walking students through concepts using 3D displays, Silén et al. (2008) describe using 4D MR images of the heart pumping for demonstrating complex phenomena when the technology is too advanced for students to work with alone. Yet, discussion of 3DVT in instructor-centered methods is limited in the literature, and this study provides additional examples of how faculty use 3DVT during lectures to clarify topics or engage students, and integrate questions into activities as a way to get students thinking about clinical relevance. Additionally, participants highlighted how time constraints associated with lectures and demonstrations can be prohibitive to the use of 3DVT.

Faculty who use 3DVT in interactive instructional processes involve students in participatory activities which help facilitate their learning, while those who use 3DVT in experiential learning involve students in activities where they perform tasks in realistic clinical settings. Preclinical participants in this study described using 3DVT in a variety of interactive activities, including discussions surrounding case studies, group projects that students completed using the technology, and peer-teaching in small lab groups. While Brown et al. (2012) describe using 3D models of aortic aneurisms to lead interactive discussions, little research has examined or described how 3DVT can be used in interactive instructional processes. Additionally, while use of 3DVT in experiential learning activities such as simulations (Arora et al., 2012; Willaert et al., 2012) and laboratories (Nieder et al., 2000; Adamczyk et al., 2009; O'Rourke et al., 2020) has been described, articles discussing the integration of 3DVT into clinical settings are deficient. Yet, participants in this study describe how they believe the use of 3DVT in natural settings is important because patient care is the end goal and they want students to apply their learning in clinical-like settings whenever possible.

Faculty also use 3DVT for individualized learning activities where students complete targeted modules which guide their learning in specific areas. While participant discussion of 3DVT use for modularized instruction was minimal in this study, similar discussion in the literature is disproportionately extensive. A vast majority of articles describing the creation or assessment of 3DVT involve instructional modules that students complete on their own. For example, a large number of the study designs compare outcomes of student who complete 3D versus 2D based computer tutorials (Nicholson et al., 2006; Donnelly et al., 2009; Hampton and Sung, 2010; Hu et al., 2010; Keedy et al., 2011; Metzler et al., 2012; Tan et al., 2012; Müller-Stich et al., 2013; Yeom et al., 2017). Yet only two participants described using 3DVT for individualized learning, including a guided walkthrough of a virtual reality model, and an application reviewing content already taught in a 3D virtual laboratory. Neither of these examples represents the type of isolated learning on computer tutorials like those described in many studies.

### Implications: Designing and Assessing Use in Instructional Processes

Educators designing medical curricula that include the use of 3DVT need to carefully consider the type of instructional processes to be used. Examples of use from participants in this study, as well as descriptions in the literature, suggest that a number of factors can impact the decision of what type of instructional process to use. For example, when looking to get students to practice concept application faculty tend to incorporate 3DVT into experiential settings, while when they want to demonstrate the clinical relevance of content they utilize questioning. Similarly, Silén et al. (2008) describe how they selected demonstrations when content was difficult or they wanted to gain student attention, and then provided self-study modules to allow for deeper exploration through direct student interaction with models. This demonstrates how selection of instructional processes to be used with 3DVT can depend on the content or learning goals, and thus the use of multiple processes may be necessary within a given curriculum.

This study also brings attention to an important concern that faculty have related to time limitations inhibiting use of 3DVT. Administrators should consider that some faculty may choose not to use 3DVT in certain instructional processes, such as lectures or demonstrations, due to limitations in time to cover a certain amount of content. If conclusive evidence is found that 3DVT is best used in these ways, administrators will need to consider how they can make the time needed for faculty to use it in this way. Additionally, administrators should consider how they can support faculty development which would provide training to help instructors learn to quickly navigate use of the technology during sessions and make the most efficient use of time.

Those planning how to structure instructional processes utilizing 3DVT should include careful consideration of existing evidence related its effectiveness in different types of activities. For example, Brown et al. (2012) reported that feedback on their demonstrations of aortic aneurisms indicated that students wanted to also access the material outside of class for additionally self-study. However, Silén et al. (2008) reported that many of their students had not accessed self-study materials, even when it was close to examinations, and that student comments indicated that they wanted more help learning to interpret images, either from a tutor or written explanations with arrows. This suggests that while students are receptive to the idea of individualized learning, faculty including these activities should ensure students have the necessary support to learn to use them and carefully plan how to encourage students to complete them.

While decisions on the instructional processes to be used with 3DVT should be based on evidence, this study highlights that there are still significant gaps in the literature. While a majority of studies use computer tutorials to examine the effectiveness of 3DVT, none of the faculty in this study described using this type of independent learning activity. While these studies are designed to allow for more direct comparison of 3D and 2D learning, if this does not represent the way 3DVT is being used in actual settings then the findings do little for adding to the understanding of 3DVT effectiveness in relevant contexts. Faculty participants in this study described providing independent learning activities as a supplement to other activities utilizing 3DVT, so studies are needed to assess the effectiveness of 3DVT use in this way. Similarly, additional studies are needed to examine the effectiveness of 3DVT in the different types of learning activities described by this study, and to elucidate the relationship between the use of various types of learning activities and learning outcomes.

*Evaluation*

Faculty use 3DVT in a variety of ways to assess student learning, and many of these methods are also described in the literature by those who have designed studies to test the effectiveness of 3DVT. However, most of these studies are conducted in isolated settings, and this study offers additional context by providing faculty accounts of 3DVT use for assessment in various medical curricula. The themes for this curricular element provide additional framing for discussing faculty use of 3DVT for either summative or formative assessment. Furthermore, this study highlights the current limitations of 3DVT use for assessment and describes the perceived difficulties faculty face in designing assessment.

Descriptions of 3DVT use for summative evaluation of student learning are minimal, both in this study and in the literature. Similar to participant descriptions in this study, others have described using static screenshots of 3D models to create structure identification questions (Hisley et al., 2008; Cui et al., 2017); however, these tests were for research purposes and did not impact students' actual grades. Hisley et al. (2008) additionally describe questions that required students to complete spatial ordering of screenshots or identify structures based on movies of rotating volumetric models. Descriptions in this study and the literature suggest these types of questions are generally limited to first order identification questions or second order functional/clinical application questions.

The use of simulation for assessing knowledge and skills has been described by participants and authors alike, and both agree that while it offers promise, the use of simulators for summative assessment should be approached with caution. For example, Arora et al. (2012) emphasize the importance of feedback that surgical simulators can provide, stating, “Built in, objective skills assessment provides meaningful performance measures that guide psychomotor and procedural skills development”, yet they failed to find an acceptable level of face validity of the temporal bone simulator they examined. While proper validation of simulators for use in summative assessment may be difficult, faculty still find simulators to be a valuable tool for providing students with formative feedback. O'Leary et al. (2008) describe using network connections between simulators to allow for interactions between trainee and trainers, and report that the simulator improved learners ability to identify structures and articulate surgical approaches. Similarly, participants in this study describe implementing instructor feedback during the use of simulators to help further guide student learning.

Other formative assessment methods for which faculty describe utilizing 3DVT include self-quizzing and in-activity questions. In their study of learning preferences, Adamczyk et al. (2009) reported that students ranked the quiz modules second on the list of advantages of a multimedia tool, behind only the 3D models. Several authors and preclinical participants in this study have described using 3DVT which provides students the opportunity to assess their understanding using a quizzing function (Nieder et al., 2000; Trelease and Rosset, 2008; Yeom et al., 2017). While some have described utilizing quizzes, others have explained how the integration of questions into activities helps highlight additional points which students should consider. Metzler et al. (2012) and Müller-Stich et al. (2013) both describe the creation of teaching modules covering anatomy of the liver that required students to answer questions before they were able to continue moving through the module, but these were limited to simple click-to-identify questions. This study provides additional context related to faculty use of in-activity questions, such as participants who described using clinical questions during lab to prepare students for questions they might encounter in clerkships.

While some faculty use 3DVT for the assessment of student learning, many also explain that the challenges associated with designing adequate assessment limit its use. In their review of the quality of research on 3D models, Azer and Azer (2016) note the absence of a validated knowledge assessment tool in many studies. Additionally, McGaghie et al. (2010) note that one of the biggest challenges in simulation-based medical education is designing outcome measurements, though this is not specific to 3D simulations. While participants in this study describe facing similar challenges of designing valid assessment items and simulation metrics, their explanations also highlight how faculty face limitations of testing software which do not easily allow for incorporation of 3D content or videos.

The challenges associated with designing assessment using 3DVT has led many faculty and researchers to utilize other methods for evaluating student obtainment of knowledge and skills. Researchers and participants have both described using multiple choice questions (Dobson et al., 2003; Donnelly et al., 2009; Hu et al., 2010; Hopkins et al., 2011; Keedy et al., 2011; O'Rourke et al., 2020) and 2D imaging identification questions (Metzler et al., 2012; Nguyen et al., 2012; Müller-Stich et al., 2013) as alternative methods for testing students' factual and spatial anatomical understanding. Additionally, postgraduate participants described using performance-based evaluation for assessing residents. Similarly, Rengier et al. (2009) describe a case-based learning approach where clinical students were required to complete diagnostic reports which included a diagnosis, differential diagnoses, and secondary findings.

**Implications: Supporting and Designing Effective Assessment**

Evaluation of student learning is a critical component of the curriculum and faculty must carefully consider the design of assessment and how it might influence student approaches to learning. This study demonstrates that a number of faculty use methods other than 3DVT for assessment, yet this lack of inclusion may have important impact on how students choose to utilize 3DVT for learning. Observations by Hopkins et al. (2011) revealed that just prior to the studies posttest, students often abandoned use of 3D models in labs and instead resorted to memorization of facts on paper-based handouts. Furthermore, in their discussion of anatomy education Inuwa et al. (2012) stress the importance of including technology in assessment, stating that "innovation should include the adoption of sound pedagogy as well as the use of technology in teaching and assessing the subject" (p. 23). If faculty want students to gain deeper levels understanding from their use of 3DVT, then the assessment they use needs to move beyond simple recall, and they need to find creative ways of using 3DVT for testing students ability to integrate and apply knowledge and clinical information.

While careful design of assessment is critical, this study has described a number of challenges that faculty face when designing assessment methods using 3DVT. If administrators want to support the integration of 3DVT into the curriculum, then they need to find ways to support faculty in designing effective assessment tools. Administrators need to find ways to offer faculty training and resources which support the development of rigorous, validated assessment methods that include the use of 3DVT. Additionally, administrators need to ensure faculty are provided the necessary technology and support required for using 3DVT in assessment of student learning.

Continuing research into 3DVT should also consider the importance of assessment and how it affects students' learning. The findings by Hopkins et al. (2011) that students altered their study strategy to match the assessment tool suggests further research is needed to understand how assessment affects student use of 3DVT. More information on the link between assessment methods and student interaction with 3DVT is needed by faculty who must make decisions about how best to design assessment, but also by researchers who design studies assessing the effectiveness of these technologies. In their discussion, Hopkins and colleagues (2011) point out the potential problem of current methods of assessment in research, stating:

> The methods often used for testing the efficacy of our innovations may, in fact, be undermining our understanding of the impact of these

> innovations on learning because they assess students using testing methods that encourage them to default to individual learning activities that have been used for generations (p. 886).

Further, it has been noted that most studies examining 3DVT lack a validated assessment tool (Azer and Azer, 2016). Continuing research needs to address these limitations in assessment to provide meaningful evidence of 3DVT effectiveness.

*Comparison of Use*

While the published literature contains a considerable number of articles assessing and describing uses of 3DVT, something that has not been explored or discussed is the comparison of use of 3DVT for anatomy education at various levels of the medical curriculum. One aim of this study was to address this gap, and Figure 4.19 illustrates the similarities and differences of use found between the preclinical and postgraduate levels. Results indicate that faculty use of 3DVT included similarities in use as a resource, intended learning outcomes, content covered, arrangements of learning experiences, and difficulty experienced with assessing student learning.

The primary differences found for 3DVT use as an instructional resource included that only preclinical faculty use 3DVT for integration, and they more frequently discussed using 3DVT to show pathologies, typically for the purpose of integration of clinical content. On the other hand, postgraduate faculty use of 3DVT was focused on specific pathologies of a specialty and creating low-risk training or team training opportunities.

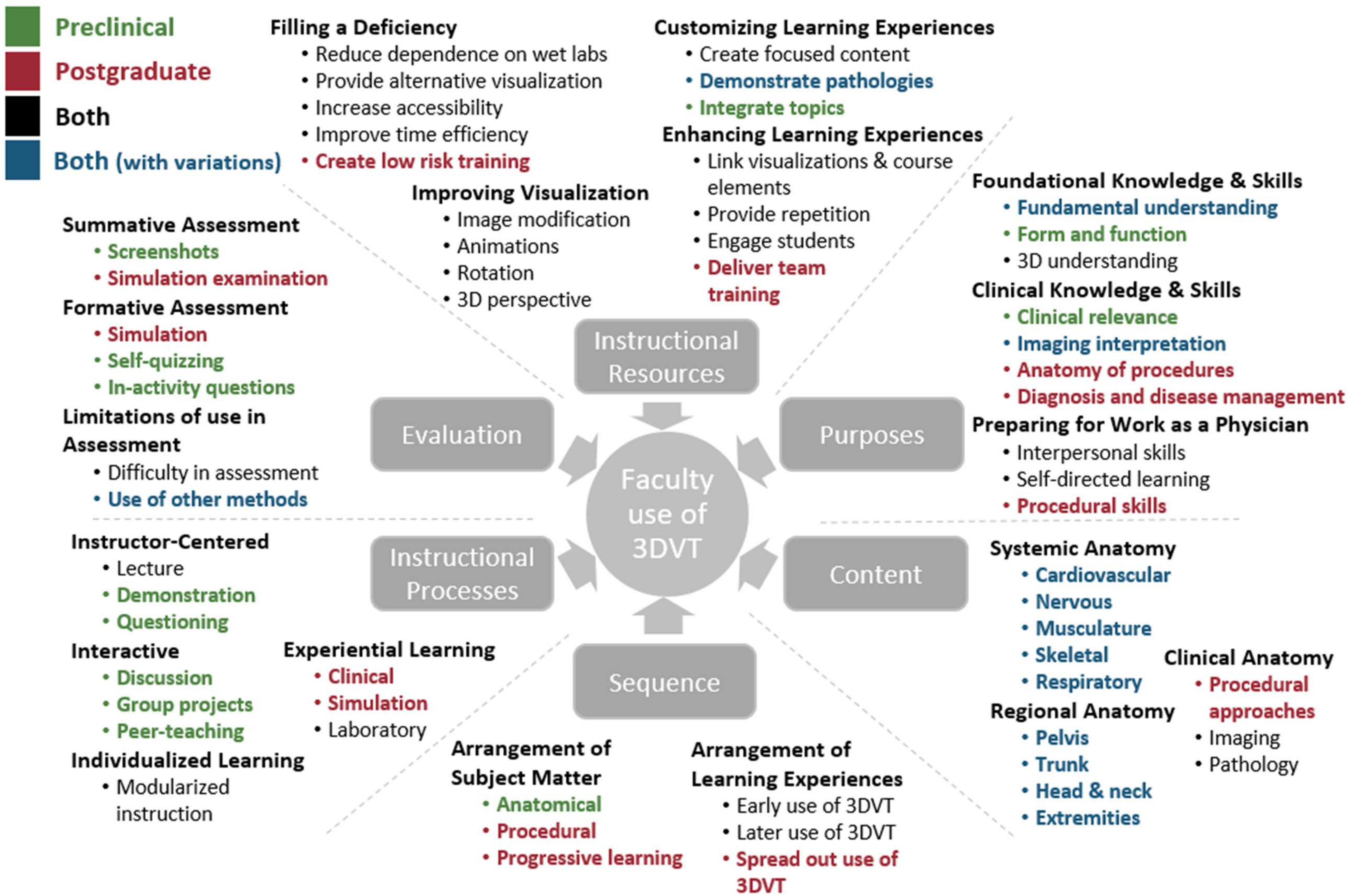



Figure 4.19: Similarities and Differences of 3DVT Use

Differences in curricular purposes included that preclinical faculty were primarily the ones to focus on teaching form and function, clinical relevance, and correlation of normal anatomy with imaging. Conversely, postgraduate participants focused more on reviewing fundamental concepts in the context of clinical experiences, interpretation of patient scans, anatomy of specific procedures, diagnosis and disease management, and development of procedural skills.

While the systemic, regional, and clinical anatomy content taught by faculty at different levels was largely the same, preclinical participants tended to focus more on general, widely applicable subject areas, while postgraduate participants taught content more specific to their specialty. For example, preclinical faculty talked about teaching nerves and their innervation, while postgraduate faculty teach about specific nerve lesions encountered in the clinic. Additionally, only postgraduate faculty described teaching content related to procedural approaches.

There was a fair amount of variation in how faculty from different levels talked about sequence of the curriculum and 3DVT use. Not surprisingly, only preclinical faculty described arranging subject matter based on systemic or regional anatomical divisions. Meanwhile, only postgraduate participants describe arranging subject matter according to specific procedures, or to allow for progressive learning. Also, while both preclinical and postgraduate faculty described arranging learning experiences to include early or later use of 3DVT, only postgraduate faculty described spreading out the use of 3DVT.

While both preclinical and clinical participants described including 3DVT use in lectures, laboratories, and individualized learning modules, the rest of the instructional processes were only described by one group or the other. Preclinical participants often described instructor-centered methods such as demonstrations and questioning, or interactive methods, including discussion, group projects, and peer-teaching. On the other hand, postgraduate participants described using 3DVT in experiential learning, such as clinical experiences and simulations. The use of more authentic clinical settings makes sense for postgraduate education, where advanced training requires opportunities for residents to practice applying knowledge and skills. Additionally, these experiential methods are inherently interactive, making the other types of processes less necessary.

While both preclinical and postgraduate participants described having difficulty designing assessment, each group varied in the types of assessment they used. Preclinical participants described using self-quizzing and in-activity questions for formative assessment, while postgraduate participants relied on simulation. For summative assessment preclinical participants that use 3DVT rely on screenshots, while, again, postgraduate participants utilized simulation. Finally, when not using 3DVT for summative assessment preclinical participants described using multiple choice and medical imaging questions, while postgraduate participants relied on performance evaluation.

**Implications: Use Across Levels of the Medical Curriculum**

In preclinical medical education students build a foundation of anatomical knowledge, and then progressively build on this as they move through clinical and postgraduate levels of their training. Some have expressed concerns about the level medical graduates anatomical knowledge, such as Marks Jr (2000) who stresses:

> Potential new 3-D technology is increasingly more difficult to teach to postgraduate physicians because of escalating inadequacies in their learning, testing, and using 3-D images of the human body during undergraduate medical education (p.449).

Administrators and educators involved in planning 3DVT use should consider if longitudinal integration of technology across the curriculum can be used to help students develop knowledge and skills necessary for postgraduate training. Understanding the different ways faculty use 3DVT across the levels of the curriculum may provide clues about how it can be more seamlessly integrated to meet the needs of learners at multiple levels of the curriculum.

This study demonstrates that faculty at different levels are largely using 3DVT in similar ways, thus administrators may be able to consider how one technology could be utilized by students as they move through medical education. For example, the 3DVT that students use for learning fundamental anatomy at the preclinical level could be used again for reviewing this foundational knowledge when they start postgraduate training. By using the same technology costs may be reduced, as well as the cognitive load on students who do not have to learn new technology at each level. Similarly, faculty at multiple levels use 3DVT for supplementing other resources to try to increase access, make efficient use of time, reduce time in labs and operating rooms, and provide new and improved means of visualizing anatomy. Administrators should look at these, and other areas of similarities, to consider if 3DVT can be implemented for similar uses at multiple levels.

In cases where faculty use of 3DVT differs across the curriculum the ability for customization may allow for the technology to change with the needs of different levels. The coronary modules created by Friedl et al. (2002) provide an example of how content can be customized to increase in complexity, where preclinical students can learn basic cardiovascular anatomy, and residents can learn techniques for specific procedures. Similarly, 3DVT could be used to teaching normal anatomy followed by pathology, regional anatomy followed by procedural anatomy, or normal imaging followed by patient specific scans. Educators should explore the potential of 3DVT to be used as a tool that can aid in spiraling the curriculum, where students are able to use the same program throughout their training as it continually evolves to present increasingly complex topics, and moves from foundational anatomy to specific clinical knowledge and skills.

Finally, the results of this study highlight a stark difference in the use of simulation, which suggests that educators may need to consider more carefully how it is integrated throughout the medical curriculum. None of the preclinical participants of this study described use of simulation, yet postgraduate participants described using simulation as an instructional process, as well as a tool for formative and summative assessment. If residents are using simulation as part of their training and high stakes examinations, it may be beneficial to expose medical students to the use of simulators earlier in the curriculum. This earlier exposure could give them a chance to become familiar with the use of simulators and help lower the learning curve they must face when starting postgraduate training.

**Limitations**

While attempts were made to include a representative sample of participants and to minimize potential sources of bias, there remain some limitations to this research. The potential limitations of this study include the lack of clinical participants, transferability of the results, inter-rater reliability, and self-selection bias.

*Lack of Clinical Participants*

The lack of clinical participants in this study may mean the results are missing representation from one area of the medical curriculum. The lack of responses from clinical faculty could mean the recruitment materials were not seen, people chose not to respond, or the use of 3DVT at the clinical level was limited. The recruitment material was shared in a variety of ways, but visibility may have been limited by the fact that the listservs available are not directly aimed at clinical faculty. Of clinical faculty who were contacted directly, some did not respond, while others indicated that their institutions did not use 3DVT. Given that Spencer et al. (2008) reported that only 19% of US schools and 24% of Canadian schools included basic science courses during the clinical years, it could be that there is limited time for anatomy education with 3DVT to occur. The questionnaire created by this study could be used to further explore the prevalence of 3DVT use for anatomy education in the clinical curriculum.

*Transferability*

Given the small sample size of participants in this study there may be some limitations to the transferability of the findings to other settings. Of note, this study only included participants from North America, so the transferability of results to international settings may be limited. Those looking to generalize the results of this study to other institutions should carefully evaluate whether the settings and curriculum are similar enough to those described in this study to allow for comparison (Lincoln and Guba, 1985). The rich descriptions and participant quotations included in the results helps to provide details which help with such comparisons. Additionally, the wide variety of participants included in this study, including faculty from different regions and specialties, who use different types of 3DVT, increases the likelihood that the results are transferable to other settings. Finally, the questionnaire created in this study can be implemented in future research to further examine the generalizability of these findings.

*Inter-Rater Reliability*

While some studies include the use of another researcher to code part or all of the data set in order to compare coding and determine inter-rater reliability, this was not used in the current study. With the use of semi-structured interviews, and the constant comparative method, the researcher becomes deeply familiar with the data in a way that cannot be taught to another coder. Superficial coding may result from the need to create simplified definitions for the purpose an inter-rater reliability check (Morse, 1997).

*Self-Selection Bias*

The primary recruitment method of posting on listservs and mailing contacts introduces the potential for self-selection bias. It may be that the participants who responded to the recruitment letter and agreed to participant are inherently interested in 3DVT. These participants may be more inclined to have positive perceptions of 3DVT and use it differently than those who did not participate. Yet, the limited population of potential faculty who use 3DVT reduced the options for recruitment, and a rich variety of specialties and regions was included to increase the diversity of perspectives.

**Future Directions**

This study was the first to (1) provide a framework for understanding how faculty use 3DVT for anatomy education in the medical curriculum, (2) compare this use across the preclinical, clinical, and postgraduate levels, and (3) provide a tool for quantitively examining faculty use of 3DVT. While this study provides a deeper understanding of how faculty incorporate 3DVT into multiple elements of the curriculum, there remains several key areas that future research should address, including exploration of additional curricular elements, quantitative examination of study themes, and further assessment of 3DVT based on the gaps identified in this study.

While this study explored faculty use of 3DVT in relation to many of the curricular elements defined by Lattuca and Stark (2011), there are additional academic plan elements that were outside the scope of this study and which warrant further research. This study did not explore the learners of medical curricula, or how faculty consider 3DVT use in relation to specific groups of medical students. Further research is needed to better understand how 3DVT use impacts different groups of learners and how faculty plan for addressing the needs learners who will use 3DVT. Additionally, this study did not explore program evaluation or adjustment related to 3DVT use. Further research could explore how faculty and administrators evaluate courses and programs which utilize 3DVT, and how they make changes to curricula based on experience and evaluation.

This study qualitatively examined faculty use of 3DVT in order to inform the development of a framework based on participant experiences. While this initial exploration was important for providing an in-depth understanding of phenomenon not well described in the literature, a subsequent quantitative analysis using the questionnaire created in this study could provide additional information on the generalizability of the findings. A pilot test is needed to evaluate the validity of the questionnaire so that future work can utilize it as a tool for quantitative studies of 3DVT use. This would allow future work to examine the prevalence of the 3DVT use themes presented in this work and provide additional means for comparing use across the levels of the curriculum.

While this study provides insights into how faculty use 3DVT, it does not provide information on the effectiveness of these uses. In order to inform evidence-based integration of 3DVT into the medical curriculum, a systematic evaluation of the current research on 3DVT is needed. Further work is needed to examine the current evidence on the effectiveness of 3DVT in relation to the various elements of the curriculum. Organizing an analysis of 3DVT effectiveness according to individual components of the curriculum would provide insights into what elements of curricular design may impact effectiveness and offer evidence to inform suggestions for best practices of 3DVT use.

However, as mentioned previously, sufficient research assessing 3DVT is lacking, and a broader scope of assessment is needed for a more comprehensive understanding of the interplay between curricular elements and effectiveness of 3DVT as a teaching tool. This study highlights a number of areas where research on the effectiveness of 3DVT is lacking, and continuing assessment of the effectiveness of 3DVT as a teaching tool needs to encompass the elements of 3DVT use described in this study (Figure 4.20). Assessment of 3DVT as a teaching tool needs to include studies which examine how successful it is in augmenting other resources, improving visualization, and aiding in customization and enhancement of learning experiences. Continuing assessment of 3DVT also needs to examine a range of learning outcomes and content areas, as well as compare effectiveness of different types and arrangements of learning experiences. Finally, more studies are needed to understand how student learning should be assessed and how these assessment measures impact student use of 3DVT.

This study has identified an extensive number of gaps in the current literature related to the assessment of 3DVT effectiveness. Since addressing all these areas would require an unrealistic number of studies, identifying areas of greater importance could help focus future work. A survey of 3DVT use based on the questionnaire created in this study could help provide data on the areas of use most common among current medical curricula. This would help inform the areas of 3DVT use that assessment should then focus on in order to inform practices relevant to the widest population. Additionally, an evaluation of current research, as described above, would likely further highlight key gaps in the existing research.

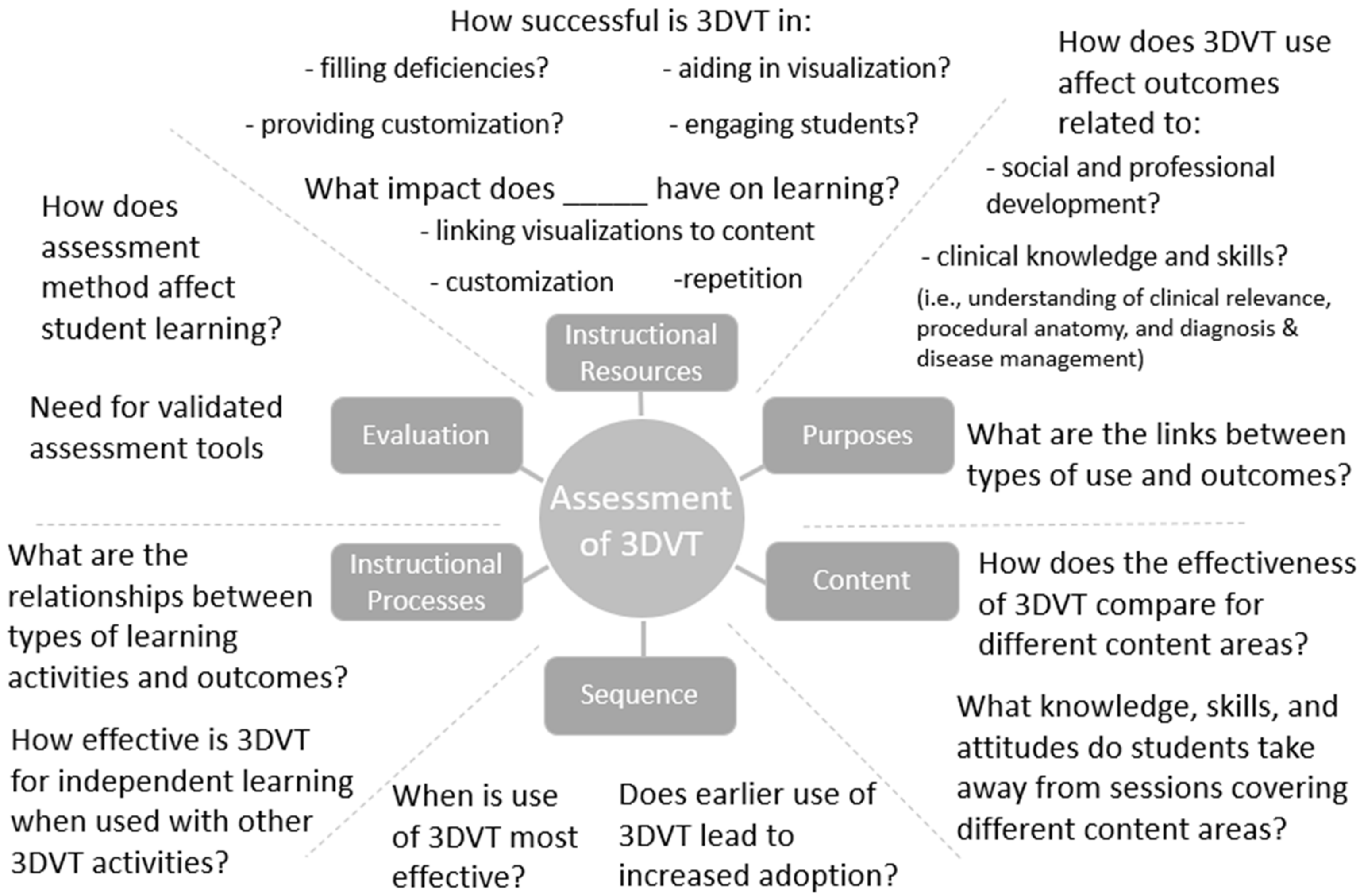



Figure 4.20: Areas for Continuing Assessment of 3DVT

**Conclusions**

Examining how faculty use 3DVT for anatomy education plays a fundamental role in understanding medical curricula and the effectiveness of 3DVT as an instructional tool. The results of this study provide a framework of 3DVT use which can be used for more productive assessment of 3DVT and for helping inform discussions regarding implementation of 3DVT into the curriculum. This study demonstrates that 3DVT is being is implemented in a variety of ways in the curriculum, thus continuing assessment of the effectiveness of 3DVT as a teaching tool should encompass the many aspects of 3DVT use described in this study. Assessment of 3DVT as a teaching tool needs to include studies which examine how successful it is in filling the types of deficiencies described by participants and improving students' ability to visualize complex anatomy. Additionally, assessment needs to examine how customization of instructional activities impacts student learning and determine to what extent 3DVT use impacts student engagement.

This study also demonstrates that faculty use 3DVT for trying to help students develop a wide range of knowledge, attitudes, and skills, and assessment of 3DVT needs to further examine the relationship between these learning outcomes and the specific uses of 3DVT. Additionally, this study highlights how research needs examine the effectiveness of 3DVT for teaching specific content and explore how the coverage of certain topics is related to student learning. Further research is also needed to better elucidate the relationship between the timing of 3DVT use and student learning, preparedness, and likelihood to adopt technology. The results of this study also indicate that more comprehensive research is needed to understand the effectiveness of 3DVT in different types of learning activities, particularly the use of independent learning activities provided as supplements to in-person 3DVT use. Finally, not only does continued research need to include the use of validated assessment items, but additional insight is also needed regarding how the choice of assessment method impacts students use of 3DVT.

The results of this study not only inform future assessment of 3DVT, they also provide insight for educators and administrators who are involved with planning 3DVT integration in a medical curriculum. Educators should consider how they can leverage the abilities of 3DVT to address needs beyond just improvement of learning. Those looking to use 3DVT should carefully consider the learning objectives they are trying to meet, and then decide what content conveys the appropriate knowledge, attitudes, and skills, what sequence and instructional process would be most effective for those goals, and what assessment method adequately evaluates student attainment of those goals. The results of this study also indicate that administrators who want to support the integration of 3DVT into the curriculum need to provide adequate support for faculty, such as by providing sufficient time for activities to include use of 3DVT, creating training to help faculty learn to navigate the tools quickly, and ensuring faculty have the training and resources necessary for designing valid assessment methods using 3DVT.

## APPENDIX A: RECRUITMENT MATERIALS

### Recruitment Letter

Dear Members,

If you use three-dimensional technology for medical education I would like to offer an opportunity for you to share your experiences. My name is Shannon Helbling and I am a PhD student in the Anatomy & Cell Biology Education Track Program at Indiana University School of Medicine. As part of my dissertation research, I am conducting a qualitative study about how faculty use three-dimensional technology for anatomy education in preclinical, clinical, and postgraduate medical curricula. This information will be used to develop a framework for more productive discussions about assessment and integration of such technologies within medical education.

Full-time basic science and clinical faculty who have used three-dimensional technologies in education at a US medical school and/or residency program are invited to participate. Your experiences can markedly contribute to understanding how faculty approach integrating three-dimensional technologies into various components of medical curricula and help characterize differences in three-dimensional technology use.

Faculty experiences represent a valuable addition to the understanding of three-dimensional technology use, which is why I am asking and would be very grateful for your participation in my study. Please follow the link below to complete a brief form that will allow me to discern whether you fulfill the criteria to be a member of my study population. Additionally, please feel free to forward this letter to others who may be interested in participating.

https://iu.co1.qualtrics.com/jfe/form/SV_ezmDjmet2wvitVz

**Please complete this form by February 15th, 2019**

If you are selected and agree to be a participant in this research, you will be asked to take part in an online, one-on-one audio recorded interview of approximately 45-60 minutes in duration. Your participation in this research is completely voluntary. Please see the Study Information Sheet for more detailed information:
https://iu.box.com/s/h4e24r8hfb9ywarzqbf78m8o6e4i7d1f

I appreciate your consideration.

Shannon Helbling
PhD Candidate
Indiana University School of Medicine
Department of Anatomy and Cell Biology

**Participant Screening Questionnaire**

INDIANA UNIVERSITY

English

**Three-dimensional visualization technology in the medical curriculum: Exploring faculty use in preclinical, clinical, and postgraduate anatomy education**

Thank you for your interest in being a study participant. Exploring faculty experiences using three-dimensional (3D) technology for medical education will significantly add to the current understanding of how such technologies are integrated into different components of the medical curriculum. If you are interested in participating please respond to the following short questionnaire so that your eligibility to be a participant can be determined. Your personal information will be kept confidential and if you are selected to participate all data will be deidentified.

To answer the questions on this form you will need to consider a 3D technology that you have used for medical education. 3D technology encompasses a broad range of educational tools, and for the purposes of this study we are interested in any type of 3D visualization technology. A 3D visualization technology utilizes computer modeling to bring a visual dimension to an object to provide 3D visualizations of the human body. This includes 3D static images, animations, and apps, as well as interactive programs that allow for interaction with volumetric models. It also includes technology or devices that provide 3D learning environments such as augmented or virtual reality. However, the scope of this study does NOT include 3D printing of models.

If you have any questions or concerns regarding this study you can contact Shannon Helbling at

INDIANA UNIVERSITY

English

Please briefly describe one three-dimensional (3D) technology you have used for medical education (i.e., in preclinical basic science course work, clinical clerkships, or postgraduate residency programs).

At what institution was the 3D technology you described used?

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INDIANA UNIVERSITY

English

In what program or course did you include the use of 3D technology? If use was in a clinical clerkship or residency program please indicate the field of specialty.

Please briefly describe the primary student population (e.g., year of study, number of students, etc.).

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INDIANA UNIVERSITY

English ▼

Please leave any additional information that you would like us to know in the space provided below.

Please enter your first name and last name in the form below.

First Name

Last Name

Please provide an email address so that we can contact you regarding your eligibility to participate.

‹‹ ››

INDIANA UNIVERSITY

We thank you for your time spent taking this survey.
Your response has been recorded.

## Study Information Sheet

INDIANA UNIVERSITY
SCHOOL OF MEDICINE

IRB Protocol # 1808221275

### STUDY INFORMATION SHEET

### Three-dimensional visualization technology in the medical curriculum: Exploring faculty use in preclinical, clinical, and postgraduate anatomy education

You are invited to participate in a qualitative study exploring how faculty use three-dimensional technology within the preclinical, clinical, and postgraduate medical curriculum. This information will be used to develop a framework for more productive discussions about assessment and integration of such technologies within medical education. Full-time basic science and clinical faculty of U.S. medical schools are invited to participate. Your experiences as a faculty member can markedly contribute to understanding and identifying how three-dimensional technologies are implemented for anatomy education within the medical curriculum. We ask that you read this form and present any questions you may have before agreeing to be in the study.

This study is being conducted by Shannon Helbling from the Indiana University School of Medicine, Department of Anatomy and Cell Biology, and Laura Torbeck from the Indiana University School of Medicine, Surgery Chairman's Office.

STUDY PURPOSE

The purpose of this study is to explore and describe how faculty use three-dimensional technologies for education in the medical curriculum at three levels: a) preclinical coursework b) clinical clerkships and c) residency programs. Particular attention will be paid to how faculty consider different aspects of the curriculum when implementing three-dimensional technologies for anatomy education. Examination of the different approaches to using three-dimensional technology will help shed light on the reasons behind the successes or failures of their use as a teaching tool. Additionally, a deeper understanding of the different ways in which preclinical, clinical and postgraduate faculty approach 3D technology use will help facilitate productive conversations and inform curriculum reform. With a better understanding of 3D technology use across all levels of medical education, policy makers, administrators, and faculty will be better equipped to make informed decisions about future directions of technology use.

PROCEDURES FOR THE STUDY:

As a potential participant in this study, you are eligible to participate in a single one-on-one interview. The interview will occur at the beginning of the year (January-March 2019). Participants will be asked to discuss their experiences with 3D technology use in medical education.

If you agree to be in the study, you will take part in a single one-on-one interview:

> Participants will be interviewed once and will only be asked for an additional one-on-one interview if it is deemed necessary by the researchers and consent is provided. If you do not wish to answer any of the questions for any reason, you do not have to answer and the researchers will move onto the next question. All interviews will be audio-recorded and transcribed at a later date. One-on-one interviews will last approximately 30 minutes.

CONFIDENTIALITY

Efforts will be made to keep your personal information confidential. You will have an identification number and a pseudonym to protect your identity. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published. Only the researchers will have access to the data. The interviews will be audio-recorded and the audio recordings and transcriptions will be stored on secure Box account. Files will only be accessed on a password protected computer from the researcher's office. Following completion of the study the researchers will delete the audio recordings from the interviews. Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigators, the Indiana University Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP).

PAYMENT

Upon completion of the interview you will receive a 50$ prepaid Visa gift card.

CONTACTS FOR QUESTIONS OR PROBLEMS

For questions about the study, please contact the researcher Shannon Helbling at  or

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects Office at

VOLUNTARY NATURE OF STUDY

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Again, you do not have to answer any question or take part in the study if you feel the questions are too personal or if talking about them makes you uncomfortable. Your decision of whether or not to participate in this study will not affect your current or future relations with the IU School of Medicine.

# APPENDIX B: INTERVIEW PROTOCOL

1. INTRODUCTIONS
    a. Introduce myself & protocol
        i. PhD student in the Anatomy & Cell Biology Education Track Program at Indiana University School of Medicine
        ii. My use of 3D technology led to a curiosity of what others were doing.
        iii. Protocol: questions; private closed-door office; audio recorded
        iv. Questions for researcher
    b. Their introduction
        i. Can you tell me a bit about yourself and your background?
2. QUESTIONS
    a. Tell me about your teaching responsibilities at ____(institution)_____

        Probes:

        - Tell me about the course/program that you teach in and what type of anatomy education is included
    b. You said that you use __(technology)__ in your course/program. Can you tell me a little more about that software/app/etc.
    c. I'm curious about how you use this technology in your __________ course/program. Could you describe an example of when you used __(technology)_ in your course, such as an in-class activity or assignment.

        Follow up questions:

        - What were you hoping the students would take away from this lesson?
        - Are there other places students can use or access the 3D technology?
        - Besides ___(example given)_____, are there other types of course activities your students/residents do using this 3D technology?

d. Describe a time when you used a 3D technology and felt its use was successful

   Follow up question

   - Describe a time when you used a 3D technology and felt its use was unsuccessful

e. I would like to hear about your experience implementing this technology into your course/program. Could you walk me through the process you went through as you worked to integrate ___(technology)____ into your curriculum?

   Probes:

   - Can you describe some decisions you had to make when thinking about how to use ___(technology)____ within your course/program?
     - Were there any other decisions you had to make?
   - Are there aspects of your course/program curriculum that you had to consider when first implementing the 3D technology?
     - You talked about ___, and _____. Are there any other aspects of the curriculum you had to consider?
   - What types of factors influence the way you use 3D technology in your program/class?

f. When you think about education at the ___(preclinical, clinical, graduate)____, what do you see as the goals of education in your program/class?

   Probes

   - What do you feel is the purpose of anatomy education at your level?

   Follow up question

   - How do you use __(technology)___ to achieve these goals?

g. Are there specific areas or types of subject matter that you cover when teaching with 3D technology?

   Probe

   - Are there certain knowledge, skills, or attitudes you hope students will take away from their use of the 3D technology?

h. I would like to hear about how 3D technology use fits into the timing of your course. Can you talk about when in your program/class 3D technologies used? For example, are they used to introduce material, or for reviewing content already covered?

i. Can you talk about the role of 3D technology in assessment for your course/program?

   Probe

   - Do you use __(technology)__ to evaluate student learning?
   - How do you asses if students obtained the necessary knowledge or skills from use of the 3D technology?

j. What do you see as the benefits of 3D technology use?

   Follow up question

   - What do you see as the difficulties of 3D technology use?

k. Is there anything else you would like me to know about your experience using __(technology)____ in your course/program?

3. Conclusions

   a. I really appreciate you taking the time to speak with me about your use of 3D technology. You have done some exciting things in your course/program, and I have enjoyed talking with you about your experiences.

   b. I will be contacting participants after I complete the analysis to share my findings. I will be generating a survey based on the major themes from these interviews and I would welcome any feedback you have about how well you feel the items reflect your experience with 3D technology use.

APPENDIX C: DEVELOPED QUESTIONAIRRE

**IMPORTANT:**

For the purposes of this survey three-dimensional visualization technology (3DVT) is any technology that utilizes computer modeling to bring a visual dimension to images of the human body. This includes stereoscopic images viewed with 3D glasses, as well as 3D static images, animations, and interactive applications viewed on a 2D screen (so long as the image has visual cues to provide some sense of depth). It also includes technology or devices that provide 3D learning environments such as augmented or virtual reality.

3DVT **DOES NOT** include 3D printed models as these are physical models rather than visualizations.

Considering any 3DVT that you have used for medical education, how much do you agree or disagree with the following statements?

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| I have used 3DVT to reduce the need for wet labs (e.g. replacing or supplementing cadaver and/or animal skills labs). | ○ | ○ | ○ | ○ | ○ |
| I have used 3DVT to provide an alternative way for students to visualize anatomy. | ○ | ○ | ○ | ○ | ○ |
| I have used 3DVT to increase student access to tools for learning. | ○ | ○ | ○ | ○ | ○ |
| I have used 3DVT to increase the efficiency of student learning (i.e., reduce learning time). | ○ | ○ | ○ | ○ | ○ |
| I have used 3DVT to make time in learning sessions more efficient (reduce procedural time) | ○ | ○ | ○ | ○ | ○ |
| I have used 3DVT to create learning opportunities that minimize risks to patients. | ○ | ○ | ○ | ○ | ○ |

How useful are each of the following 3DVT functionalities for providing students with an ideal visualization of the anatomy being learned?

| | Not at all useful | Slightly useful | Moderately useful | Very useful | Extremely useful | *Not Applicable* |
|---|---|---|---|---|---|---|
| Adding or removing structures | ○ | ○ | ○ | ○ | ○ | ○ |
| Altering transparency | ○ | ○ | ○ | ○ | ○ | ○ |
| Altering coloration | ○ | ○ | ○ | ○ | ○ | ○ |
| Isolating specific structures | ○ | ○ | ○ | ○ | ○ | ○ |
| Animations | ○ | ○ | ○ | ○ | ○ | ○ |
| Rotation | ○ | ○ | ○ | ○ | ○ | ○ |

How useful is the 3D perspective provided by 3DVT for giving students an ideal visualization of the anatomy being learned?

| Not at all useful | Slightly useful | Moderately useful | Very useful | Extremely useful |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

To what extent do you use 3DVT to do the following?

| | Not at all | A little | Some | Quite a bit | Very much |
|---|---|---|---|---|---|
| Create customized learning materials (e.g. alter visualizations to focus on relevant content, exclude structures not specific to the lesson, etc.) | ○ | ○ | ○ | ○ | ○ |
| Create customized lesson plans (e.g. using the technology to guide students through sequential steps). | ○ | ○ | ○ | ○ | ○ |
| Show students pathology. | ○ | ○ | ○ | ○ | ○ |
| Integrate content from other basic science areas of the curriculum (i.e., histology, physiology, etc.) | ○ | ○ | ○ | ○ | ○ |
| Integrate clinical content with anatomy being taught. | ○ | ○ | ○ | ○ | ○ |

How much do you agree or disagree with the following statements about 3DVT use in your curriculum?

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| The 3D visualizations are frequently linked to other instructional resources (textbooks, informational videos, teaching modules etc.) | ○ | ○ | ○ | ○ | ○ |
| The 3D visualizations are frequently linked to additional content (i.e., structure information, clinical correlates, or medical images). | ○ | ○ | ○ | ○ | ○ |
| 3DVT is used because it allows for easy repetition of activities. | ○ | ○ | ○ | ○ | ○ |
| 3DVT is used to engage students in learning experiences. | ○ | ○ | ○ | ○ | ○ |
| 3DVT is used with multiple people for team training. | ○ | ○ | ○ | ○ | ○ |

How important to you are the following student learning outcomes from the use of 3DVT?

| | Not at all important | Slightly important | Moderately important | Very important | Extremely important |
|---|---|---|---|---|---|
| Fundamental understanding of anatomy (i.e., the identification of structures and description of the human form and its organization) | ○ | ○ | ○ | ○ | ○ |
| Knowledge of form and function (i.e., the ability to connect human structure with how things work and why things happen) | ○ | ○ | ○ | ○ | ○ |
| 3D understanding of anatomy (i.e., visuospatial understanding of the human form, how the body is arranged, and the 3D relationship of structures) | ○ | ○ | ○ | ○ | ○ |
| Understanding the relevance of anatomy in the context of clinical settings | ○ | ○ | ○ | ○ | ○ |
| The ability to apply anatomical knowledge to the interpretation of medical imaging | ○ | ○ | ○ | ○ | ○ |
| Knowledge of procedural anatomy (understanding anatomy as it relates to specific procedures so that structures can be safely examined, accessed, or navigated around) | ○ | ○ | ○ | ○ | ○ |
| Understanding of diagnosis and disease management | ○ | ○ | ○ | ○ | ○ |

How important is student achievement of the following skills during their use of 3DVT?

| | Not at all important | Slightly important | Moderately important | Very important | Extremely important |
|---|---|---|---|---|---|
| Teamwork | ○ | ○ | ○ | ○ | ○ |
| Leadership | ○ | ○ | ○ | ○ | ○ |
| Communication | ○ | ○ | ○ | ○ | ○ |
| Self-directed learning | ○ | ○ | ○ | ○ | ○ |
| Procedural (competence in the physical and practical skills of clinical care) | ○ | ○ | ○ | ○ | ○ |

To what extent do you cover the following content areas using 3DVT?

| | Not at all | A little | Some | Quite a bit | Very much |
|---|---|---|---|---|---|
| Heart | ○ | ○ | ○ | ○ | ○ |
| Blood vessels | ○ | ○ | ○ | ○ | ○ |
| Peripheral nerves | ○ | ○ | ○ | ○ | ○ |
| Central nervous system | ○ | ○ | ○ | ○ | ○ |
| Muscles | ○ | ○ | ○ | ○ | ○ |
| Bones | ○ | ○ | ○ | ○ | ○ |
| Respiratory structures | ○ | ○ | ○ | ○ | ○ |

To what extent do you cover the following regions using 3DVT?

| | Not at all | A little | Some | Quite a bit | Very much |
|---|---|---|---|---|---|
| Pelvis | ○ | ○ | ○ | ○ | ○ |
| Abdomen | ○ | ○ | ○ | ○ | ○ |
| Thorax | ○ | ○ | ○ | ○ | ○ |
| Head & neck | ○ | ○ | ○ | ○ | ○ |
| Extremities | ○ | ○ | ○ | ○ | ○ |

To what extent do you cover the following topics using 3DVT?

| | Not at all | A little | Some | Quite a bit | Very much |
|---|---|---|---|---|---|
| Procedural approaches (content related to specific surgical approaches, examination procedures, or other procedures used for patient care) | ○ | ○ | ○ | ○ | ○ |
| Imaging interpretation | ○ | ○ | ○ | ○ | ○ |
| Pathology | ○ | ○ | ○ | ○ | ○ |

How much do you agree or disagree with the following statements about the **organization of the content taught in your curriculum?**

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| Subject matter is arranged regionally (pelvis, abdomen, head & neck, etc.) | ○ | ○ | ○ | ○ | ○ |
| Subject matter is arranged systemically (respiratory, cardiovascular, reproductive, etc.) | ○ | ○ | ○ | ○ | ○ |
| Subject matter is arranged according to specific procedures. | ○ | ○ | ○ | ○ | ○ |
| Subject matter is arranged progressively, with simple topics covered first followed by increasingly complex topics. | ○ | ○ | ○ | ○ | ○ |

How much do you agree or disagree with the following statements about **3DVT use in your curriculum?**

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| 3DVT is primarily used early in the learning process (e.g., for introducing topics or allowing students to preview material prior to other types of sessions). | ○ | ○ | ○ | ○ | ○ |
| 3DVT is primarily used later in the learning process after students have built a base understanding of material using other methods. | ○ | ○ | ○ | ○ | ○ |
| 3DVT use is spread across learning experiences. | ○ | ○ | ○ | ○ | ○ |

About how often do you incorporate 3DVT into the following instructional methods?

| | Never | Sometimes | About half the time | Most of the time | Always | **Instructional method not used |
|---|---|---|---|---|---|---|
| Lectures | ○ | ○ | ○ | ○ | ○ | ○ |
| Demonstrations | ○ | ○ | ○ | ○ | ○ | ○ |
| In-class questions | ○ | ○ | ○ | ○ | ○ | ○ |
| Discussions | ○ | ○ | ○ | ○ | ○ | ○ |
| Group projects | ○ | ○ | ○ | ○ | ○ | ○ |
| Peer-teaching | ○ | ○ | ○ | ○ | ○ | ○ |
| Clinical experiences | ○ | ○ | ○ | ○ | ○ | ○ |
| Simulations | ○ | ○ | ○ | ○ | ○ | ○ |
| Laboratories | ○ | ○ | ○ | ○ | ○ | ○ |
| Self-study modules | ○ | ○ | ○ | ○ | ○ | ○ |

About how often do you use the following methods for integrating 3DVT into **summative** assessments (grades, end of unit evaluations, measurements of proficiency, etc.)?

| | Never | Sometimes | About half the time | Most of the time | Always | Not Applicable |
|---|---|---|---|---|---|---|
| Using screenshots of 3D images to create assessment items | ○ | ○ | ○ | ○ | ○ | ○ |
| Using 3D simulation for summative assessment | ○ | ○ | ○ | ○ | ○ | ○ |

About how often do you use the following methods for integrating 3DVT into **formative** student assessments (providing feedback for improvement, on-going evaluations, monitoring progress, etc.)?

| | Never | Sometimes | About half the time | Most of the time | Always | Not Applicable |
|---|---|---|---|---|---|---|
| Using 3D simulation for formative assessment | ○ | ○ | ○ | ○ | ○ | ○ |
| Providing students with 3D technology that includes a self-quiz function | ○ | ○ | ○ | ○ | ○ | ○ |
| Incorporating questions into activities involving 3DVT use | ○ | ○ | ○ | ○ | ○ | ○ |

In your experience, how difficult are the following activities related to the assessment of student learning?

| | Not difficult at all | Slightly difficult | Moderately difficult | Very difficult | Extremely difficult |
|---|---|---|---|---|---|
| Designing effective assessment of student learning | ○ | ○ | ○ | ○ | ○ |
| Incorporating 3DVT into assessment tools | ○ | ○ | ○ | ○ | ○ |

About how often do you use methods other than 3DVT for the assessment of student learning?

| Never | Sometimes | About half the time | Most of the time | Always |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

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CURRICULUM VITAE

**Shannon Amara Helbling**

## EDUCATION

**Doctor of Philosophy:** Anatomy and Cell Biology — Jan. 2021

Minor: Education
Indiana University, Indianapolis, Indiana
Dissertation Title: Three-Dimensional Visualization Technology in the Medical Curriculum: Exploring Faculty use in Preclinical, Clinical, and Postgraduate Anatomy Education

**Bachelor of Science**: Molecular Biology and Biotechnology — May 2015

University of Idaho, Moscow, Idaho
Honors: Summa Cum Laude

**Bachelor of Science**: Business Administration Management — Aug. 2011

San Jose State University, San Jose, California

## TEACHING EXPERIENCE

**Washington State University Elson S. Floyd College of Medicine**

Foundations of Medical Science I: FMS 501 — 2019-Current
Clinical Senior Instructor

- Director of Histology
- Assistant Director of Anatomy

Foundations of Medical Science I: FMS 501 — 2018
Visiting Scholar

- Lecturer
- Lab instructor

**Indiana University School of Medicine – Associate Instructor**

Neuroanatomy: Contemporary and Translational: ANAT-D 527 — 2019

- Guided graduate students through neuroanatomy labs

Systems Approach to Biomedical Sciences: D515 — 2017-2019

- Developed and delivered 2 lectures on muscle physiology

Neuroscience and Clinical Neurology: MED 852 — 2017-2019

- Guided students through neuroanatomy lab sessions

- Facilitated team-based learning sessions where student groups worked through clinical case studies and imaging exercises

Translational Neuroscience: ANAT-D 701 2017
- Guided physical therapy students through neuroanatomy labs
- Facilitated team-based learning sessions to help students work through case studies

Humane Structure: MED-X620 2016-2017
- Assisted medical and physical therapy students with cadaveric dissection and structure identification
- Aided students with the identification of structures in laboratory using light and virtual microscopes
- Worked with the course director to complete biweekly lab prosections
- Assisted with the set-up, proctoring, and grading of the laboratory practical examinations
- Provided lecture on cranial cavity, meninges, and dural venous sinuses

Human Gross Anatomy: ANAT-D 501/528 2016-2017
- Assisted graduate (D501) and physician assistant (D528) students with cadaveric dissections and the identification of relevant structures
- Developed and delivered 3 lectures on the abdominal cavity
- Completed biweekly cadaver prosections prior to each lab (Spring 2017)
- Helped with the set-up, proctoring, and grading of the laboratory practical and written examinations

**Indiana University-Purdue University Indianapolis (IUPUI) – Adjunct Instructor**
Human Anatomy: BIOL N261 2015-2016
- Created and delivered 12 pre-laboratory lectures on relevant histological and gross anatomical structures
- Guided undergraduate students through the study of the human body using light microscopes, models, photographs, and non-cadaveric dissections
- Wrote, proctored, and graded laboratory examinations
- Organized and maintained laboratory course management site and gradebook

**Washington Wyoming Alaska Montana Idaho (WWAMI) Medical Education Program – Teaching Assistant**
Head & Neck Anatomy MED SCI 531 2014
Trunk Anatomy: MED SCI 511 2013
- Assisted medical student groups with dissection and structure identification
- Conducted study sessions with students for exam preparation outside of class time

**University of Idaho**
Human Physiology: BIO 121 2014-2015
Lab Coordinator

- Worked directly with teaching assistants to coordinate instruction across 8 laboratory sections, and co-taught two laboratory sections of 25 students
- Supported teaching assistants in the writing, proctoring, and grading of laboratory exams

Human Anatomy: BIO 120 2013-2014
Lab Coordinator

- Worked directly with teaching assistants to coordinate instruction across 11 laboratory sections, and co-taught two laboratory sections
- Facilitated teaching assistant preparation of cadaver prosections
- Supported teaching assistants in the writing, proctoring, and grading of laboratory exams

Human Anatomy: BIO 120 2012
Teaching Assistant

- Assisted undergraduate students with the identification of relevant structures on bones, prosected cadavers, heart dissections, and models
- Aided course instructor with cadaveric prosections
- Wrote, proctored, and graded laboratory practical examinations

RESEARCH EXPERIENCE

**Undergraduate Research Fellowship** 2013
Institutional Development Award Network of Biomedical Research Excellence (INBRE)
Topic: Copper Complexes as Models for Alzheimer Plaque Catalysts of RSNO Decomposition

- Synthesized model compounds to study the effects of nitric oxide in the progression of Alzheimer's disease

POSTERS/PRESENTATIONS AT PROFESSIONAL MEETINGS

**Creating Interactive Online Modules** May 30, 2018
Workshop Presenter
HAPS 32nd annual conference
Columbus, Ohio

**A Cadaveric Prosection for Demonstrating the 12 Cranial Nerves in Situ** May 29, 2018
Workshop Presenter
HAPS 32nd annual conference
Columbus, Ohio

**Hands-on Histology for Active Learners** May 28, 2017

Workshop Presenter
HAPS 31st annual conference
Salt Lake City, Utah

**Demonstration and Use of Bodyviz as a Teaching Tool** Aug. 24, 2016

Seminar Presenter
Anatomy Educational Seminar
Department of Anatomy and Cell Biology
Indiana University School of Medicine

**Membrane Transport and Membrane Potential to Get Your Students Active in Lab** May 24, 2016

Workshop Co-Presenter
HAPS 30th annual conference
Atlanta, Georgia

**Copper Complexes as Models for Alzheimer Plaque Catalysts of RSNO Decomposition** Aug. 6, 2013

INBRE Summer Research Conference
Moscow, Idaho

PROFESSIONAL DEVELOPMENT

**Human Anatomy and Physiology Society Annual Conference**

Attended update speaker seminars, poster sessions and workshops for the following HAPS conferences:

San Antonio, Texas May 2015
Atlanta, Georgia May 2016
Salt Lake City, Utah May 2017
Columbus, Ohio May 2018

**Anatomical Education Research Institute**

Volunteered at the sign in desk and attended speaker presentations

Bloomington, Indiana July 2017

PROFESSIONAL ORGANIZATION MEMBERSHIPS

American Association for Anatomy 2014-Current
Human Anatomy and Physiology Society 2014-Current
American Association of Clinical Anatomists 2018-Current

SERVICE

**Japanese Implant Practice (JIP) Society** 2017-2018
Prosector
Indiana University School of Medicine

**Clinical Anatomy M.S. Program** 2016
Volunteer Tutor
Indiana University School of Medicine

**HAPS Testing Committee** 2016-2017
Committee Member
Human Anatomy and Physiology Society

**Indiana University Center for Anatomical Sciences Education (IU-CASE)**
Gross Anatomy Laboratory Tour Instructor 2015-2019
Volunteer at Celebrate Science Indiana 2015
Indiana University School of Medicine

**WWAMI Anatomist Search Committee** 2014
Committee Member
University of Idaho

**Make a Difference Day & Saturday of Service** 2012-2014
Site Leader
University of Idaho

**Teaching and Advising Committee** 2012-2014
Student Representative
University of Idaho

AWARDS AND HONORS

**Dean's Award** May 2015
College of Science
University of Idaho

**Primal Pictures and Human Anatomy and Physiology Society Scholarship Award** May 2015
Haps 29$^{th}$ Annual Conference
San Antonio, Texas

**Alumni Award for Excellence** Dec. 2014
University of Idaho

**Mary Dechois Kamberos Scholarship** 2014
University of Idaho

**Leslie Bengston M.D. Memorial Scholarship** 2013
University of Idaho

**Dean's List** 2012-2014
University of Idaho