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Investigating the User Experience with a 3D Virtual Anatomy Application

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by

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We hereby certify that this dissertation, submitted by Winnyanne Kunkle conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Submitted to Nova Southeastern University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Decreasing hours dedicated to teaching anatomy courses and declining use of human cadavers have spurred the need for innovative solutions in teaching anatomy in medical schools. Advancements in virtual reality (VR), 3D visualizations, computer graphics, and medical graphic images have enabled the development of highly interactive 3D virtual applications. Over recent years, variations of interactive systems on computer-mediated environments have been used as supplementary resource for learners. However, despite the growing sophistication of these resources for learning anatomy, studies show that students predominantly prefer traditional methods of learning and hands-on cadaver-based learning over computer-mediated platforms.

There is limited research on evaluating user experience in the use of interactive 3D anatomy systems, even though Human-Computer Interaction (HCI) studies show that usability (ease of use) and user engagement are essential to technology adoption and satisfaction. The addressable problem of the research was to investigate how ease of use and flow affected aspects of the students' engagement experience with the use of a 3D virtual anatomy application. The aim of the study was to evaluate the use of a 3D virtual application in performing dissection learning tasks and to understand aspects of user engagement as assessed by ease of use and flow experience.

The flow experience was quantified using the Short Flow State Scale (S FSS-2) and the System Usability Scale (SUS) to measure perceptions about ease of use and user satisfaction. The research questions included: (1) What consequences of flow do students experience? (2) What aspects of the 3D virtual platform are distracting to performing the learning tasks? (3) How do students' perception of ease of use affect the flow experience based on the SUS and S FSS-2 scores? (4) How do students rate their level of engagement as measured by flow based on their S FSS-2 scores? (5) How does flow help explain student satisfaction and motivation? (6) How do students perceive use of the application to learn anatomy compared with cadaver-based dissection?

The study consisted of medical student participants who were asked to complete virtual dissection activities associated with learning objectives in the Structure of the Human Body course to perform using a 3D virtual anatomy application. A subset of participants who completed the learning task and the surveys had a follow-up Cognitive Walkthrough with Think-Aloud Protocol observation activity with an interview segment to gain deeper insights into their user experience with the application.

The data from the convergent mixed method analysis indicated that ease of use had some impact on the flow experience and that perceived user satisfaction and motivation were attributed to the interactive 3D visualization design. Seven super-ordinate themes were identified: Ease of Use, Learnability, Interface-Technical, User Satisfaction, Visuospatial, Focus/In the Zone, and CA vs Cadaver.

The results have implications for educators (particularly anatomists), educational technologists, and HCI and UX practitioners. Additional research should be conducted using the long version of the Flow State Scale to provide a better understanding of each flow dimension. Further study is recommended with students who have hands-on experience with human cadaver dissection that are also able to compare their experience with the use of a 3D virtual anatomy platform for a direct side-by-side assessment. It would also be helpful to conduct the study as part of the entire duration of the anatomy course and assess how the flow experience impacts student learning performance.

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This study was developed out of curiosity for understanding the human experience with use of technology and the intrigue that the study of Human-Computer Interaction (HCI) has inspired in me. I am forever grateful to several individuals who have provided support and guidance throughout the process of completing this dissertation journey.

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Chapter 1

Introduction

Background

Anatomy education provides medical students an in-depth understanding of the structure and function of the human body, locations and inter-structure spatial relations. Understanding anatomy is essential to the practice of health and medicine. The Florida International University Herbert Wertheim College of Medicine (FIU HWCOM) medical students learn anatomy during the first two years through traditional pedagogical methods consisting of didactic lectures, prosections, plastinated anatomical parts, and multimedia presentations. The students have the option in a fourth-year anatomy elective for human cadaver dissection learning. Students have advocated for supplementary resources for learning anatomy that incorporate a hands-on, interactive and realistic 3-dimensional (3D) solution as a response to limited access to cadaver dissection during the first two years of their medical education. In response to the need, HWCOM introduced a 3D virtual anatomy application installed on iPads and laptops as a resource for the anatomy course for all medical students.

The medical students' desire for supplementary learning resource in response to lack of access to cadaver-based anatomy learning is not unique to the FIU HWCOM. The medical curricula have seen a decline in anatomy teaching hours and diminishing or complete removal of cadaver labs across medical schools in undergraduate teaching over the last 2-3 decades (Memon, 2018). Medical school curriculum has emphasized the importance of hands-on clinical experience which, in turn, has shortened the hours taught for pre-clinical anatomy classes

(Rizzolo et al., 2010). However, decline in anatomy course hours has not minimized the need for students to learn the same anatomy knowledge. The reduction of hours in the basic sciences curricula in teaching anatomy and the diminished capacity for cadaver-based learning have spurred the need for an innovative approach to teaching and learning strategies to maximize students' learning of anatomy (Azer & Eizenberg, 2007).

Human Cadaveric Dissection Learning Experience

Cadaveric dissection remains an essential component of anatomy teaching in most medical schools (Davis, Bates, Ellis, & Roberts, 2014). Cadaver-based anatomy learning has been considered the gold standard for learning anatomy. Older (2004) described the dissection as an invaluable experience because it helps develop manual dexterity for clinical practice, exposes students to anatomical variations, and promotes teamwork and awareness of human morbidity and mortality. Similar experiences were also conveyed among second year medical students in their musculoskeletal system dissection (Flack & Nicholson, 2018). Dissection also provides a starting point for humanistic education where students learn to form an empathetic connection with whom they imagined the donor could be, fostering connectedness and reflection, which can lead to empathetic clinicians (Dissabandara et al., 2015; Rizzolo, 2002).

Further advantages of dissection include providing students the hands-on experience and helping students build a 3D mental image of anatomical parts through the process of exploration and curiosity brought on by active observation and participation in dissection (Flack & Nicholson, 2018; Gunderman & Wilson, 2005; Pawlina & Lachman, 2004). The ability of dissections to provide an authentic learning experience which engages all the senses enable students to understand anatomical structure spatial relationships that 2D representation typically cannot (Lu et al., 2017). The process of dissection helps reinforce and elaborate knowledge acquired in traditional lectures and tutorials (McLachlan et al. 2004). Despite the many

advantages of learning anatomy based on dissection, there are several factors that have contributed to its decline and use: the increasing cost of cadavers and required facilities, preservation requirements, sense of repulsiveness some students experience when working with cadavers (Petersson et al., 2009; Raja, 2020), recognition that cadavers do not have the same coloration as their living counterparts (Lu et al., 2017), and ethical implications of cadaver donations (Gunderman & Wilson, 2005).

The need for cadaver-based dissection in the medical curriculum continues to be debated. At a debate in a symposium entitled, "Do we really need cadavers any more to learn anatomy in undergraduate medicine?" (McMenamin et al., 2018), the audience was evenly split on the need for cadavers to teach anatomy to medical undergraduate students. Given the majority (80%) were originally in favor of the use of cadavers before hearing the opposing arguments, the facilitator considered the "No we do not" house as winner of the debate. Raja (2020) suggested that cadaver experience is not essential based on evidence showing the equivalency of exam scores (United States Medical Licensing and clinical skills exams) between students who had cadaver dissection and those without.

Technology Advancements in Anatomy Tools

Innovations with interactive 3D virtual anatomy platforms have garnered increased interest among educators and researchers on its effectiveness and potential with teaching anatomy compared with other modalities (Alharbi et. Al, 2020; Iwanaga et al., 2021; Stirling & Moro, 2020; Zhao et al., 2020), especially in times of the COVID-19 pandemic (Inawaga et al., 2020; Onigbinde et al., 2020). Over the decades, educators have turned to technology-based solutions as gross anatomy instructions rely less on cadaver dissections (Gunderman & Wilson, 2005; Sugand et al., 2010) and as medical education programs feel increasing pressure to teach more information in less time (Battulga et al., 2012; Boscolo-Berto et al., 2021). Advancements in

information and communication technology (ICT) and interactive computer graphics models have shown a potential to help achieve anatomical understanding in less time as these technologies can provide interactive 3D representations of anatomy (Battulga et al., 2012; Kurul et al., 2020).

Use of medical imaging such as magnetic resonance imaging (MRI) and computed tomography (CT) in the medical curricula can be attributed to its representation of living anatomy and use in the clinical practice (Grignon, 2016). MRI and CT images can provide highly detailed images of the internal anatomy and capture a wider variety of pathology and morphology that static postmortem cadavers cannot (Gunderman & Wilson, 2005). Medical curricula have used diagnostic imaging to enable students to visualize the structure and function of human anatomy. The 3D structures of human anatomy are often taught in 2D platforms which can be challenging for medical students to mentally convert into their 3D version and gain a better understanding of their spatial relationship (Battulga et al., 2012). The use of imaging in teaching anatomy provides a unique understanding and visualization of the spatial relationship between anatomical structures (Curley et al., 2017).

A wide range of e-learning and computer-aided learning (CAL) resources focused on anatomy tutorials is available to students from passive viewing web-based applications to highly interactive 3D virtual systems. Virtual anatomy systems feature a range of interactive capabilities to provide a high level of user engagement (Preim & Saalfeld, 2018). Essential features of a virtual anatomy system include the ability to rotate, pan and zoom images. Advanced interaction techniques involve planar clipping and slicing to separate anatomical regions for in-depth examination.

Preference for Cadaver-based Learning

Despite the variety of e-learning, computer-aided learning resources, and virtual anatomy systems offering the tools for interactive engagement, students show an overwhelming preference for cadaveric dissection and traditional methods of learning (Davis et al., 2014; Preim & Saalfeld, 2018). Davis et al.'s (2014) study showed that student and faculty participants strongly favored access to cadaveric specimens and small group teaching methods. Year one students were less enthusiastic about the anatomy web-based e-learning resource compared to year two students. The authors indicated the difference between both years on their use of the e-learning resources to be attributed to year two students' progressive desire for self-directed learning compared with year one students who needed to acclimatize and adapt to become more independent learners.

The preference for cadaver dissection has also been attributed to fostering an emotional, psychological and symbolic relatedness (as a rite of passage for medical students). Educators have emphasized the importance of understanding how 3D virtual anatomy systems compare with such feelings as of being "different and special from other peers" (Anandhi et al., 2016, p. 2), motivated (Meguid &Khalil, 2016), and feeling a sense of exploration and curiosity (Pawlina & Lachman, 2004) that is associated with cadaveric dissections.

User Experience

Human-Computer Interaction (HCI)researchers recognize the need to conduct a holistic evaluation of computer-mediated environments. User Experience (UX) research focuses on creating meaningful interactions between users and technologies by accounting for users, system, and situational elements of experience (O'Brien, 2010) and has emerged as a comprehensive

concept providing a holistic perspective on user's interaction with technology (Minge & Thuring, 2018).

Principles of HCI such as usability and engagement have been investigated to understand aspects of the user experience. Usability is considered distinct, yet interrelated with regards to UX. Usability is the ability of the user to successfully carry out a task—an outcome of an interaction, whereas UX takes a broader view of the interaction (Albert & Tullis, 2013). HCI researchers recognize the minimum level of usability needed for engagement with the system to be possible (O'Brien & Toms, 2008). The concept of engagement is multidimensional and contextual. HCI researchers have turned to a broad range of theories and frameworks to understand and measure user engagement (Doherty & Doherty, 2018). Flow has been used as a measure of user engagement across various technologies from online learning environment (Rodríguez-Ardura, & Meseguer-Artola, 2017) to gaming applications (Bressler & Bodzin, 2013) and virtual systems (Chen & Hsu, 2020).

Flow Theory

There is growing interest over the years in understanding how computer use behavior is influenced by flow. The question around what motivates users to expend time to learning and using technology has been a central question associated with studies in flow theory (Ghani et al., 1991; Guo et al., 2016). The theory of optimal flow has been proposed as a framework for investigating the experience of individuals in the process of learning and using computers, and for identifying the factors that influence the experience (Ghani, 1991). Csikszentmihályi (1990, p. 4) developed the theory of optimal flow to describe "the state in which people are so intensely involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it."

Csikszentmihályi (1975) characterized factors related to the flow experience into nine components. The first group of components, the antecedents, describes the qualifying factors of the activity for reaching the flow state: challenge-skill balance, clear goals, and immediate feedback. The second group of elements related to flow corresponds to the dimensions of the flow experience: focused concentration, merging of action and awareness (activity becomes spontaneous and nearly automatic), loss of self-consciousness, sense of control, loss of sense of time, and autotelic experience (reward).

Some consequences that have been identified of experiencing flow for computer-mediated environment include positive affect, greater experimentation, browsing and exploratory behaviors. Rodríguez-Ardura and Meseguer-Artola (2017) applied flow theory to explain how flow triggers positive emotion, performance, and continuance behavior in an online learning environment. Ghani and Deshpande's (1994) study showed that perceived task challenge and a sense of being in control were the key factors that resulted in the state of enjoyment and intense concentration--optimal flow. Flow was linked to exploratory use behavior, which in turn was linked to the extent of computer use (Carroll & Rosson, 1987; Ghani, 1991). Liao's (2006) findings indicated that flow experience could develop positive attitudes and behaviors, including intention of use and exploratory use in the context of distance learning. The finding that exploratory use resulted in longer hours at the computer is consistent with observations made by Webster (1989) and Novak et al. (1998).

Bitrián, Buil, and Catalán (2020) applied the flow theory to explore students' states of mind while playing a business simulation game. Students who were in a state of flow (skills and challenge are equally high) corresponded with the highest levels of perceived learning, satisfaction and skills development. The challenge-skill balance is related to achieving the flow

experience which is shown to improve learning performance and satisfaction in a computer-based instructional environment (Wang & Hsu, 2014). Perceived learning, flow, and enjoyment were found to be strongly and significantly correlated in a study conducted by Barzilai and Blau (2014). Flow theory was also applied to measure students' engagement with the use of mobile augmented reality (AR) learning games (Bressler & Bodzin, 2013).

The ease in which a user can interact with the application or system's interface can affect the flow state. Poorly designed interface elements can detract or disrupt the user's state of flow such as game controls lacking fluidity (Scoresby & Shelton, 2011), inconsistent navigation, disorganized content, inappropriate use of color scheme, or ambiguous labels (Pace, 2004). Flow is conducive to an optimal experience and can influence user behavior such as technology adoption and usage intention (Zhou, 2013). Zhou's (2013) investigation into mobile games adoption found perceived ease of use to affect flow; flow was shown to be positively related to usage intention.

User Experience with 3D Virtual Anatomy Platforms

UX factors are not well understood with regards to the use of 3D virtual anatomy software within the context of anatomy learning. Fundamental use factors, such as motivation to use and ease of use, are outcomes of the design of the user interface; design limitations consequently may impede increased adoption, persistent use, and success of 3D virtual anatomy systems. In a survey of literature on virtual human anatomy education systems, Preim and Saalfield (2018) stated that among four typical categories of evaluation of educational software (preference, knowledge gain, usability, behavior change), evaluation of usability is not explicitly discussed in most of the studies that investigate virtual anatomy systems from a learner's

perspective. Nuland, Eagleson, and Rogers (2017) also emphasized the lack of usability testing research in academia.

Understanding how the user interacts with the application can provide insight on learner experience and adoption which can ultimately affect the successful use of the tool. For instance, in Peterson and Mlynarczyk's (2016, p. 5) study, students perceived the human virtual dissection software program “difficult to use” and “cumbersome to study with” which appeared to impact their motivation to use the program outside the required team-based sessions, even though they found the program to be fun and highly interactive. While student performance increased, students still perceived that the use of the 3D technology did not influence their learning (Peterson & Mlynarczyk, 2016).

In Petersson et al.'s (2009) study, students’ attitudes towards the virtual anatomy program were positive compared with anatomy textbooks, but results were not the same with dissections. Less than half of the students rated the virtual anatomy program equal to, better or a lot better than dissection autopsies. Students cited advantages of the program: 3D representation and interactivity, the virtual anatomy program was odorless compared to dissections, accessibility, allowed easy location of the relevant structures, and displayed anatomical accuracy reflective of a living body. The students cited the disadvantages: lack of anatomical landmarks, surrounding structures such as muscles were not visible in the program, and lack of tactile experience.

Unrealistic representations of anatomy renderings used in some e-learning and CAL have also been attributed to its lack of adoption (Ellis, 2002). In addition, the images are presented on 2D platforms which cannot compare with 3D anatomy from cadavers (Korf et al., 2008). Grignon et al. (2016) stated that virtual dissections still need further scientific evaluation to

determine their reliability and ascertain any integrity issues dealing with the quality of medical images used with virtual dissection software despite its promising aspect as an educational tool.

Alharbi et al. (2020) found learning benefits (higher knowledge retention) in the use of a 3D-VR tool in the anatomy course. They also identified learnability and ease of use challenges that hindered the use of the tool in teaching and learning. Evaluating system ease of use as a measure of the user's perception of task-performance satisfaction (Albert & Tullis, 2013), may provide insight on noted challenges students have reported with using virtual dissection tools. Ease of Use as an attribute of Usability is subsumed by UX; it is imperative to identify usability problems, and address those problems in redesign, to improve the overall user experience (Law & Sun, 2012).

There is a need to gain a deeper understanding of the user experience with a technology-based dissection to obtain better insight on the mixed adoption results conveyed in the literature. The study aimed to examine aspects of user experience with a 3D virtual anatomy application by investigating ease of use and flow (Figure 1).

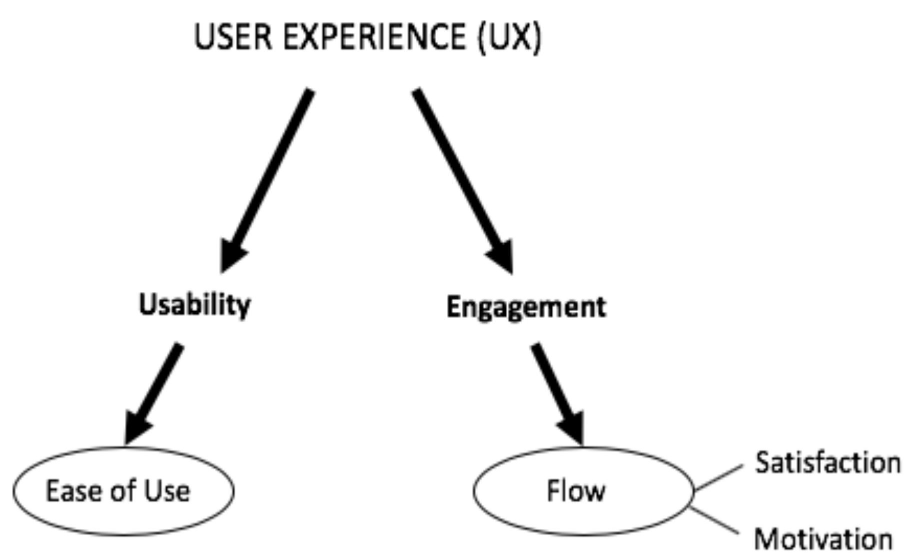


Figure 1. User Experience Diagram

Statement of the Problem, Goal, and Research Questions

Research Problem

Educators recognize the pedagogical value with incorporating 3D virtual applications for anatomy teaching as a supplementary resource; however, there are barriers to adoption of the tool that are still not well understood in the context of the UX factors. There is limited research on evaluating UX in the use of interactive 3D anatomy systems. The extent of UX evaluation was limited to usability testing assessments primarily in the initial design and subsequent redesign phases. HCI researchers have since recognized the limitations of the instrumental, task-oriented aspects of usability assessments and promote focusing on non-utilitarian qualities of the user experience (i.e. emotions, enjoyment, aesthetics, engagement, etc.) that capture the users' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011). Rather than focus solely on usability testing, this study sought to understand students' experience with using a 3D virtual anatomy application which considered ease of use and investigated flow constructs in aggregate (challenge-skill balance, action-awareness merging, clear goals, unambiguous feedback, concentration on task, sense of control, loss of self-consciousness, time transformation, and autotelic experience).

Studies including Nuland et al. (2017), Peterson and Mlynarczyk (2016) and Preim and Saalfield (2018) indicate that usability factors may impede the successful adoption of 3D anatomy tools, but existing research is inconclusive to determine what in the design of these tools affect its successful use and satisfactory experience. Flow has been linked to higher user satisfaction and motivation with interactive technologies such as gaming (Hung et al., 2012), simulation (Buil et al., 2018) and online learning environments (Esteban-Millat et al. 2014). Focused attention, a flow attribute, is also associated with level of user engagement among

mobile health app users (Holdener et al., 2020). Flow, however, is understudied in the 3D anatomy domain. A supplementary resource such as an application on mobile devices made available for students as part of their curriculum is often met with mixed adoption results. A possible explanation for these mixed results is with the level of engagement and satisfaction students experience in the use of the technology which ultimately affects their motivation to use the resource. The addressable problem of this research was to investigate how ease of use and flow affect aspects of the students' experience with the use of a 3D virtual anatomy application.

Dissertation Goal

The aim of the study was to examine use of the 3D virtual anatomy application in performing dissection learning tasks, to understand aspects of user experience as assessed by ease of use and flow. HCI researchers assert that a minimum level of usability is essential for engagement with systems to be possible (O'Brien & Toms, 2008), as such ease of use as an attribute of usability, was included in the evaluation and its effect towards the flow experience. Finneran and Zhang (2002) suggest that ease of use should be considered in evaluating flow experience within a computer-mediated environment as it has the potential to influence elements of flow.

There are numerous learning tools with similar design elements such as interactive features, 3D visualization and virtualization, yet there are varied satisfaction and adoption results among these tools as revealed in the literature. Despite the availability of these tools, there is a preference over these technology resources favoring conventional methods of learning in the classroom, namely multimedia presentations and textbooks after didactic lectures.

The researcher's desired outcome of the study was to gain a deeper insight of the HCI experience, as observed through ease of use and flow experience, among students in the use of a

3D virtual anatomy application and how the design of the tool contributes to motivation to use the tool or impede its use with learning anatomy. It was hoped that through better understanding of the students' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011), that the discussion advances on what elements of the design contribute to student satisfaction and intrinsic motivation in using 3D virtual anatomy platforms over cadaver-based dissections.

Research Questions

Educators seek to better understand how learning in the context of computer-mediated environments affects the learning experience of students. Flow has been investigated to understand students' engagement level in the use of educational tools. Flow constructs have been evaluated across different studies to understand under what conditions flow is experienced across varied technology artifacts.

This study was guided by the following research questions to investigate aspects of flow and ease of use as attributes of UX in the context of a 3D virtual anatomy domain:

1. What consequences of flow do students experience?

   Flow has been reported as a strong predictor of student's learning in the context of game-based learning (Barzilai & Blau, 2014); Bitrián et al., 2020; Bressler & Bodzin, 2013), computer-based instructional environment (Wang & Hsu, 2014), and online learning (Esteban-Millat et al., 2014; Rodríguez-Ardura, & Meseguer-Artola, 2017). Liao's (2006) study indicated that perceived flow experience had a positive significant relationship with exploratory use.

2. What aspects of the 3D virtual tool are distracting to performing the learning tasks?

Guo et al. (2016) recognized that if online learning environments were not well-designed, it may distract students from their learning tasks. Thus, the need to distinguish student's attention to the learning task versus that with distraction due to a degree of complexity with the technological elements such as game controls and inability to navigate fluidly (Scoresby & Shelton 2011). The artifact should be engaging without becoming a distraction to the user's attention to allow the user to concentrate on the higher order task (Pearce, 2005).

3. How do students' perception of ease of use affect the flow experience based on the SUS and S FSS-2 scores?

   Hung, Chou and Ding (2012) determined that a high usability and flow explained the user satisfaction of mobile gaming. Perceived ease of use was found to affect flow in a study investigating the effect of flow on user adoption of mobile games (Zhou, 2013). Ease of use as an attribute of usability can affect the user experience (Law & Sun, 2012).

4. How do students rate their level of engagement as measured by flow based on their S FSS-2 scores?

   Csikszentmihályi (1975) proposed that an important motivational process supporting sustained engagement is the experience of flow. Flow assessment has been used to measure engagement across domains from video games to educational research. Esteban-Millat et al. (2014) and Bitrián et al. (2020) studies indicate that flow is a strong predictor of student satisfaction.

5. How does flow help explain student satisfaction and motivation?

   Flow was found to be a strong predictor of satisfaction in an online learning course (Esteban-Millat et al., 2014; Shin, 2006) and in simulation games (Buil et al., 2018). Buil et al. (2018)

found that balance between skill level and challenge is key to reaching state of flow where flow is experienced in terms of having higher intrinsic motivation.

6. How do students perceive use of the tool to learn anatomy over cadaver-based dissection? Literature reveals an overwhelming preference for cadaveric dissection despite the variety of interactive 3D virtual anatomy tools (Davis et al., 2014; Preim & Saalfeld, 2018). Given the desire to understand if 3D virtual anatomy tools can ultimately replace cadavers, the researcher is interested in capturing students' perceived preference in the use of the tool in lieu of cadaver-based dissection to learn anatomy.

This study used the convergent mixed-method research approach with medical students and their use of a 3D virtual anatomy application to perform virtual dissections. The combined approach of using quantitative and qualitative data provides a better understanding of the research problems (Creswell & Plano Clark, 2007, p. 5). The convergent mixed-method is useful when the researcher wants to compare quantitative statistical results with qualitative findings for a complete understanding of the research problem (Creswell & Clark, 2017). In a mixed-method approach, the researcher collects both quantitative and qualitative data, integrates the data, then interprets the data based on the combined strength of both sets of data to understand the research problem (Creswell, 2014). Fonseca et al. (2015) found a mixed-method approach to be useful in capturing student experiences in their evaluation of student satisfaction and motivation in the use of interactive and collaborative tools with 3D architectural models.

The study consisted of a sample from a population of about 260 medical students at Florida International University with a target participant rate of 30%. Study participants were provided with learning tasks based on anatomy course learning objectives to perform in the 3D virtual anatomy application on their iPad or laptop which engaged them with the tool's

navigation menu, interactive dissection tools, and content material. It was important to select the appropriate learning tasks which support learner engagement with the activity. Mount, Chambers, Weaver, and Priestnall (2009, p. 49) points out that "engagement is difficult to achieve, no matter how technologically-advanced or well designed the learning space, if the learning activity does not engage the learner." Usability scenarios and tasks influence the issues uncovered and subsequently quality of usability testing (Russ & Saleem, 2018).

At the completion of the tasks, participants completed the System Usability Scale (SUS) (See Appendix A) to assess perception of ease of use and the Short Flow State Scale-2 (S FSS-2) scale (See Appendix B) to assess their flow experience. The S FSS-2 is designed as a post-event assessment of flow and the closer the scale is completed to the conclusion of an activity, the greater accuracy of the assessment of the state of flow experience (Jackson et al., 2010). A subset of participants who completed the surveys were interviewed individually to gain a deeper understanding of their user experience in the use of the application. Interviews also included direct observation of the user experience of the tool through conducting a usability observation method known as Cognitive Walkthrough (CW) (Mahatody et al., 2010) and a verbal facilitation technique called Think-Aloud Protocol (TAP) (Ericsson & Simon, 1993).

The flow experience was quantified based on the abbreviated version of the Flow State Scale (FSS-2), the Short Flow State Scale-2 (S FSS-2), developed by Jackson et al. (2010) and applied for use among student participants in a 3D learning experience (Bressler & Bodzin, 2013). The S FSS-2 is meant to be a holistic measure of a user's flow state. While this scale was developed and validated for measurement of sports-related activity, it has been used to measure a broad definition of flow in technology-mediated learning experience including

augmented reality (Bressler & Bodzin, 2013), and video games (Ma & Williams, 2011; Weibe et al., 2014).

Ease of use, an attribute of usability, was quantified using the System Usability Scale (SUS) by Brooke (1996) to determine its influence towards the flow experience. Interaction with systems was shown to enhance user engagement when users perceived the system easy to use (Oh & Sundar, 2016). Both S FSS-2 and SUS scales were administered following participants' completion of dissection tasks.

Semi-structured interviews of participants were beneficial to gain a deeper understanding of perceptions on the use of a 3D virtual anatomy application to learn anatomy. To delve deeper into user experience, the researcher conducted semi-structured interviews with a subset of participants who completed the surveys. The interviews included a brief observation method using CW. The focus of CW was to understand the application's learnability for new or infrequent users. A CW involves participants using TAP to verbally explain aspects of the user experience as they complete certain tasks with the tool. TAP is an observation technique that integrates well with the CW because the user's verbalizations through the walkthrough provides further insight into the participant's thought processes while performing a certain task (Barnum, 2011).

Relevance and Significance

Advancements in interactive multimedia, virtualization technology, and medical imaging continue to prompt a growing debate among educators as to whether cadaver-based dissection can be replaced by a technology-based solution for learning anatomy, particularly in view of the increasing challenges with cadaver dissections involving several factors from cost to ethical concerns. Literature review shows that 3D anatomy tools are effective supplementary resources

for cadaver-based anatomy learning. Usage of virtual dissections and 3D anatomy tools are often recommended as a complementary resource to cadaver dissection rather than to replace it (Paech et al., 2017; Alharbi et al., 2020). Other researchers (Codd & Choudhury, 2011; O'Byrine et al., 2008), however, argue that the technology does have the potential to replace cadavers in view of advancements in the quality of anatomical images, interactive capabilities, virtual and simulation technologies. While perceptions and attributes of UX (ease of use and motivation) have been recognized by researchers as possible factors influencing adoption and use of 3D anatomy systems (Saltarelli et al., 2014), research in this area has primarily been dominated by studies focused on evaluating academic performance with the incorporation of 3D virtual dissection software into the course.

Research has also focused on assessing knowledge gains (Anand & Singel, 2017) with the exposure to the use of the software and evaluating improvements with visuospatial ability (Lufler et al., 2012), or describing the prototype design and development of a 3D anatomy visualization tool (Lu et al., 2017). There is limited research on evaluating UX in the use of interactive virtual anatomy systems. The extent of UX evaluation was limited to usability testing assessments primarily in the initial design and subsequent redesign phase. HCI researchers have since recognized the limitations of the instrumental, task-oriented aspects of usability assessments and promote focusing on non-utilitarian qualities of the user experience (emotions, enjoyment, aesthetics, engagement, etc.) that captures the users' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011).

Studies are limited that evaluate how observed UX factors impact the successful use of the tool in studies (Mathiowetz et al., 2016; Saltarelli et al., 2014) which show higher academic performance and student preference when using cadavers for dissection compared with the use of

3D virtual dissection and simulation programs. Mathiowetz et al.'s (2016) study which compared a gross anatomy lab session and an online 3D virtual simulation program, AnatomyTV, aimed to determine if equivalent learning outcomes could be achieved regardless of the learning tool used. The findings showed that the gross anatomy lab group had significantly higher-grade percentages, self-perceived learning, and satisfaction than the AnatomyTV group. The authors noted that students spent less time on the AnatomyTV than with the gross anatomy lab which may have propelled the favorable outcome with the gross anatomy lab. While learning style and teaching structure was noted to have potentially influenced this behavior, the authors also considered motivation and engagement with the online virtual platform to be a factor. The findings of the study by Saltarelli et al. (2014) underscore the need to further investigate how use factors (ease of use, satisfaction, motivation) influence degree of preference for the prescribed tools.

Barriers and Issues

A barrier to this study was the use of an already commercially available 3D virtual anatomy application, Complete Anatomy by 3D4Medical. Even though studies have involved usability evaluations with single products, the single product as an evaluation tool limits the researcher to generalization about the user experience about virtual dissection and the viability of replacing cadavers with a technology solution. The design of the application creates a barrier for the researcher to control for design inefficiencies related to the user experience.

Assumptions, Limitations and Delimitations

Assumptions

One assumption is that student participants would have mobile or laptop device use literacy to complete the study. It was assumed that student participants had similar exposure to

the anatomy system as a focus of the study where the learning tasks are part of the learning objectives in the Structure of the Human Body year one course. It was also assumed that participants responded to the questionnaires honestly and participated in the study to the best of their ability.

Limitations

Several limitations were identified. The use of convenience sampling introduced sampling bias such that was not representative of the general population. The scope of the study was to evaluate the subjective user experience of a limited selection of learning objectives after the completion of the course and did not consider learning gains or learning performance. Since the data collection was limited to the student cohorts within a specific course and college, the results may not be generalizable.

Delimitations

Delimitations are constraints intentionally proposed by the researcher to provide structure to the research being conducted. In this study, the following delimitations were proposed:

- iPads and laptops were used for the learning tasks using the 3D virtual anatomy application.
- Student participants had sufficient level of understanding of the anatomy system selected for the study.

Definitions of Terms

Cognitive Walkthrough–a usability inspection technique in which evaluators examine a system to identify user interface (UI) problems (Wharton, Rieman, Lewis & Polson, 1994).

Ease of use–measurement of how easy the product is to use by its intended users (Nielsen, 2012).

Engagement–a quality of user experience that is characterized by challenge, aesthetic and sensory appeal, feedback, novelty, interactivity, perceived control and time, awareness, motivation, interest, and affect (O'Brien & Toms, 2008).

Flow–flow conceptualized as an optimal experience characterized by intrinsic motivation, deep absorption and focus, loss of awareness of time, enjoyment, and being completely immersed in an activity (Csikszentmihalyi, 1990).

Flow State Scale (FSS)–validated psychometric instrument (Jackson & Marsh, 1996) for measuring flow experience during physical activity but subsequently applied to measure the flow experience in technology-supported activities (Wiebe et al., 2014).

Human-Computer Interaction (HCI)–an interdisciplinary field concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them (Preece et al. 1994).

Learnability–refers to ease of use for a first-time user to perform basic tasks while efficiency denotes the task speed once a user becomes familiar with the design (Nielsen, 2012).

Satisfaction–the level of comfort users experience in achieving desired goals (Brooke, 2013).

Think-Aloud Protocol Protocol (TAP)–a technique used to gather usability data where the participant verbalizes their thoughts while performing a task (Ericsson & Simon, 1993).

Usability – According to ISO 9241–11:2018, usability is the extent to which a product can be used by specified users to achieve specified goals, with effectiveness, efficiency, and satisfaction in a specified user context.

User Engagement Scale (UES) – The UES is a 31-item questionnaire that examines the six dimensions of experience: perceived usability, aesthetic appeal, felt involvement, novelty, focused attention and endurability (O'Brien & Toms, 2013).

User Experience (UX)–field rooted in HCI that focuses on interaction between a person and something that has a user interface (Law et al., 2014).

List of Acronyms

- 3D–Three dimensional
- CA – Complete Anatomy
- FSS–Flow State Scale
- S FSS-2 – Short Flow State Scale-2
- TAP – Think-Aloud Protocol
- UES – User Engagement Scale
- UX – User Experience
- 3D VT – Three-dimensional Virtual Technology

Summary

The decreasing number of hours dedicated to anatomy courses in favor of earlier clinical experience for medical students in addition to limited access to human cadavers to teach anatomy has propelled educators to seek out computer-mediated or e-learning solutions. Despite the highly interactive and media rich functionality of these tools, students still predominantly prefer traditional methods of learning anatomy (e.g. didactic, cadaver-based, textbook). There is a lack of research with regards to understanding adoption factors of 3D anatomy tools from the UX perspective.

This study conducted an evaluation of the user experience in the use of a 3D virtual anatomy application to learn anatomy among medical students. The user experience was investigated as factors of ease of use and flow, to gain meaningful understanding of the interaction between the students and design the anatomy tool. A CW with TAP was conducted to observe participant's performance, response and reaction while performing the learning tasks. The participant's interaction with the 3D anatomy app was guided by the CW pre-defined tasks. As the student is performing the CW, they verbalized their thoughts as facilitated by TAP. The CW and TAP are independent usability techniques often combined to get insight into participant's thought process while performing certain a task (Barnum, 2011). A one-on-one semi-structured interview was conducted at the conclusion of the CW and TAP portion to obtain the participant's qualitative feedback on their overall experience.

Chapter 2

Review of Literature

Overview

This research drew from several areas in literature: HCI principles, UX, usability, flow as a measure of engagement, computer-aided learning (CAL), 3D visualization technology, anatomy teaching, and mixed-method approach. The literature review included criteria in support of the research goals and questions to better understand the adoption issues in the use of virtual anatomy tools. Virtual anatomy tools included in the literature review are variations of interactive 3D anatomy programs that are either web-based, stand-alone programs on the computer, and 3D visualization table (e.g. Anatomage Table). These tools have been referred to as computer-aided-learning, e-learning, and 3D virtual technology (3D VT) throughout the literature. The use of three-dimensional visualization technology (3DVT), where interactive three-dimensional (3D) models are viewed on a two-dimensional (2D) screen, has been thoroughly explored in anatomical education and research (Yammine and Violato, 2015; Erolin et al., 2019).

The definitions of an e-learning tool are numerous and are often mired in broad and ambiguous language that attempts to encompass all possible computer media used as instructional tools. Bonk and Wisher (2000) and Zhang (2005) defined e-learning tools as any interactive educational software computer program that mediates the learner's interaction with the educational material through an electronic interface that is hosted on the Internet or a local computer. However, based on a systematic literature review on e-learning, Rodrigues et al. (2019, p. 9) provided a definition, "an innovative web-based system based on digital

technologies and other forms of educational materials whose primary goal is to provide students with a personalized, learner-centered, open, enjoyable and interactive learning environment supporting and enhancing the learning processes."

The literature review starts with an overview of the role of cadaver-based dissection in anatomy courses and then moves towards technology based alternative due to its limitations coupled with the reduction of anatomy teaching hours. Studies that investigate use of CAL in the anatomy course are selected to understand general student perception of the tool and their preference for learning anatomy through virtual technology compared with other traditional methods (i.e. dissection). Then, the literature review includes an overview of the types of HCI related research conducted.

Anatomy Course and Cadaver-Based Learning

Dissection is historically thought to meet several objectives: (1) preparing medical students for their future career particularly in regard to understanding the classification and the components of the different body systems and preparing them to face death, (2) using cadavers and dissection as a learning strategy in the pre-clinical years not just lectures, and (3) mapping of bodily organs and understanding the relationship between patient's symptoms with deep-seated pathology (Azer & Eizenberg, 2007). Students may also be exposed to pathological conditions and anatomical variations during the dissecting process, which enhances their learning experience. Flack and Nicholson (2018) found that medical students not only conveyed dissection as a valuable educational tool but found the hands-on experience useful for teaching and learning anatomical knowledge and relationships, fostering teamwork and helping to cope with death and dying. With prosections, cadaveric material can be dissected to demonstrate to

students what is intended for them to see without risk of it being damaged by inexperienced hands (Codd & Choudhury, 2011).

Considered a limitation of virtual reality anatomy, students lose the tactile information when learning from a computer-generated model of the anatomy--a benefit from learning on cadaveric material. It is also held that anatomical variations cannot be effectively conveyed in computer simulations. As such, the excitement of discovering anomalies is lost when using computer simulations. It is believed that cadaver displays qualities of spatial information that other methods cannot convey (Codd & Choudhury, 2011).

While cadaver-based learning has held its long-standing reputation for being the gold standard in teaching anatomy, it has increasingly garnered widespread criticism for its limitations which has propelled educators to seek innovative alternatives. Furthermore, there is no evidence that dissection can better prepare medical students for the clinical years (Azer & Eizenberg, 2007). Raja (2020) found that medical students without cadaver dissection experience had the same scores as students who spent time with cadaver dissections. Combining pedagogical resources is considered the best way to teaching modern anatomy where multimodal and system-based approaches are integrated (Estai & Bunt, 2016).

Given the advancements in computer generated interactive 3D virtual models of human anatomy, increased attention has been given on assessing the pedagogical role of CAL in anatomy courses. Alharbi et al. (2020) and Codd and Choudhury (2011) find that CAL or 3D virtual reality is viewed as a complementary tool to traditional methods of teaching (i.e. lectures, dissections, textbooks). Educators, however, recognize that more research studies are needed to understand the standalone capability of CAL. Literature in this domain shows marked interest in the greater potential of CAL in view of advancements in the complement of technologies

(information technology, graphics, medical images, virtual reality, etc.) that produce computer generated 3D images with highly interactive capabilities.

Virtual Anatomy Compared with Traditional Teaching Methods

Use of technology in anatomy classes have increased in recent years and gaining popularity in use among medical students (Iwanaga et al., 2021), particularly with 3D visualization such as augmented reality and virtual reality to learn anatomy (Trieples et al. 2020). The 3D capabilities enable the students to view anatomy from any angle often with rich details based on the computer graphic rendering of the images. The COVID-19 pandemic has forced educators to leverage technology in times of physical distancing to facilitate teaching and learning. Iwanaga et al. (2021) encouraged educators to use multiple approaches to teaching anatomy to develop innovations to consider 3D virtual and augmented reality in addition to cadaveric dissection among other traditional methods.

Triepels et al. (2020) conducted a literature review using the Prisma statement (Moher et al., 2010) to evaluate 3D visualization methods for teaching anatomy and compared them to traditional methods (i.e. use of cadaver and textbooks) based on students' test results or feedback. The aim of the study was to assess whether use of three-dimensional visualizations helped improve medical students' understanding of anatomy and students' attitude towards its use. The majority of articles reviewed showed three-dimensional visualization to be an effective method in learning anatomy compared to traditional methods. The reviews revealed medical students also show a preference with a perceived motivation and interest in using three-dimensional visualization for learning anatomical structures.

Alharbi et al.'s (2020) mixed method study with medical students investigated the effectiveness of 3D-VR (on iPads) in knowledge retention in human anatomy courses as

compared to traditional teaching methods (using plastinated models of anatomical parts). They found that male students who used the 3D-VR tool had significantly higher short-and long-term knowledge scores compared with males who used the traditional methods. In contrast, females who used traditional methods had significantly higher short-term knowledge scores over those who used 3D-VR. The medical students described 3D-VR as a great learning tool, however, students also express the importance of cadavers and integrating these two methods for a complete learning experience. Several limitations and concerns in using 3D-VR were identified: iPad battery power shortages affecting student focus, the need for greater familiarity of the features of the 3D-VR to appreciate its full capabilities, and incidences of eye-strain and headaches while using the 3D-VR affected students' concentration.

Several studies have investigated students' perceptions of virtual anatomy platforms as well as evaluated differences in assessment performance in comparison with traditional teaching methods. Azer and Eizenberg (2007) conducted a study involving first and second year medical students to assess the student's perspective on the importance of dissection and to determine which educational tools were most helpful in learning anatomy.

Azer and Eizenberg (2007) found that first and second-year medical students regardless of their gender, academic background or citizenship agreed that dissection: (1) deepened their understanding of anatomy and provided them with a three-dimensional perspective of structures, (2) helped them recall what they learnt, (3) provided them with deep understanding and made learning more interesting, and (4) enhanced their respect towards the human body. They also found dissection (44%) as the most helpful learning method over textbooks (23%), computer-aided learning (CAL), multimedia (10%), self-directed learning (6%) and lectures (5%). Whereas, second-year students found textbooks (38%), dissection (18%), pre-dissected

specimens (11%), self-directed learning (9%), lectures (7%) and CAL programs (7%) as most useful. Neither of the groups showed a significant preference for pre-dissected specimens, CAL multimedia or lectures over dissection. Students agreed that dissection deepened their understanding of anatomical structures, provided them with a three-dimensional perspective of structures and helped them recall what they learnt. A review of the web-based multimedia program, an@tomedia, shows that it is a comprehensive, self-paced learning program for learning the anatomy. The program features dissection and imaging techniques that allows students to see how to construct and deconstruct the body.

Despite the excellent educational features in the design of the tool as recognized by the authors, an@tomedia was ranked low in student preferences. Azer and Eizenberg (2007) indicated that CAL programs are perhaps better used for material revision rather than as a primary learning tool. The study did not provide further insight as to why the CAL was not better perceived by the students compared to that to dissection, even though an@tomedia provides 3D visualization capability with dissection features. Innovations used in teaching anatomy, such as interactive multimedia resources, have not replaced students' perceptions about the importance of dissection.

O'Rourke et al. (2020) examined use of a 3D micro-CT computer model with virtual dissection capabilities with first and second medical year students to teach paranasal sinus anatomy. Students performed self-directed activities in one of two labs: traditional lab (equipped with cadaveric specimens, atlases, stylized plastic models) and 3D model using a touch screen LCD monitor. Students visualize the paranasal sinuses and explore their relationships using touch-based commands including rotate, slice, zoom and virtually dissect the skull. The findings indicated that when students were inexperienced with using the 3D computer technology, it had

an adverse effect to learning for students with greater prior knowledge of the anatomy. For students with prior experience in using 3D computer technology, it was detrimental for students with less prior knowledge of the anatomy.

Ultimately, O'Rourke et al. (2020) did not find comparative enhancements to learning anatomy with using the 3D model as an educational resource. Instead the 3D model was found to be comparable to traditional resources under the right circumstances. The key takeaways from this study include the need for training on the 3D technology, importance of student-led approach to resource utilization, and need for prior relevant anatomy knowledge when using the 3D computer technology.

Codd and Choudhury (2011) evaluated user satisfaction and learner knowledge gains using a prototype interactive 3D forearm musculoskeletal anatomy program. The aim was to evaluate the use of 3D virtual reality when compared with traditional anatomy teaching methods. The study investigated whether a virtual reality forearm would be as effective a learning resource as traditional methods of basic anatomy teaching. Three groups were identified: a "control" group (no prior knowledge of forearm anatomy), a "traditional methods" group (taught using dissection and textbooks), and a "model" group (taught solely using e-resource). The Analysis of Variance (ANOVA) showed the model group mean test score to be significantly higher than the control group (mean 7.25 vs. 1.46, $P < 0.001$) and not significantly different to the traditional methods group (mean 6.87, $P > 0.5$), indicating that there was no significant difference in knowledge gains using virtual anatomy tool versus traditional methods. This finding suggests that the resource is an effective tool in helping students learn forearm anatomy to a similar standard as traditional methods. Despite this finding, the authors did not recommend replacing traditional dissection, instead recommended the tool as a complimentary resource.

In a meta-analysis study conducted by Wilson et al. (2018) on anatomy lab pedagogies, there were no significant differences found between cadaver dissections and alternative modalities (i.e. prosections, digital media, 3D models/ modelling) in the context of short-term knowledge gains. They noted that cadaveric dissection preference among students maybe unrelated to learning achievements and more related to confidence levels and application of their anatomy knowledge.

Virtual Anatomy and Radiological Imaging

The advancements around 3D virtual technology and incorporation of CT and MRI images are providing students the anatomical spatial information. Existing medical imaging libraries have been used to create 3D virtual reality anatomy models with some success (Petersson et al., 2009; Trelease & Rosset, 2008). Reconstructing 3D models from CT and MRI scans familiarizes medical students learning anatomy with interpreting imaging techniques. Dissection helps in identification of structures along with tactile information on tissue texture. However, once any structure is cut or damaged during dissection, it cannot be reconstructed making dissection irreversible. Virtual models or dissection tables are alternative useful teaching learning tools. Commercial products now provide this capability such as Complete Anatomy and Anatomage Table. Virtual dissection features allow students to isolate different structures in 3D form, dissect, reconstruct, zoom in and out, transecting them to appreciate anatomical form and relationships.

Hassinger et al.’s (2010) study assessed the usability and perceived effectiveness of a 3D pelvic anatomy teaching module derived from MRI and CT and images and Petersson et al. (2009) assessed whether students value a 3D visualization method as a learning tool. Both studies investigated the effectiveness of an interactive 3D anatomy system with radiological

images and have shown positive and favorable reviews by students. The intersection of interactive features and radiological images have provided an experience closer to reality than ever before. Technologies, such as magnetic resonance imaging (MRI) and computed tomography scans; echocardiography; endoscopies and interventional radiology, have enhanced our understanding of a patient's symptoms, presentation and clinical signs.

The value of post-mortem dissection in undergraduate clinical medicine and its significance in interpreting a patient's symptoms and clinical signs has become less important (Azer & Eizenberg, 2007). Codd and Choudry (2011), while demonstrating that virtual anatomy can effectively facilitate anatomy learning as traditional methods, recommended that virtual anatomy tools should not replace cadaver-based dissection. The authors cited that a VR anatomy cannot effectively display variations or provide the "joy" of discovering anatomical anomalies as that with cadaver-based dissections**.** Radiological imaging is a step towards addressing this educational concern. There has been an increase in reliance on teaching anatomy using radiological images as instruction rely less on cadaver dissection (Gunderman et al., 2005).

Ellington et al. (2019) compared the effectiveness of a VR anatomy model with a traditional curriculum on the knowledge of female pelvic floor anatomy among residents. The results of the study showed that knowledge scores were not significantly increased with the VR model, however, residents perceived that the VR technology as an enhancement to short-term learning.

Usability

Nielsen (2003) described usability as the ease with which individuals can utilize a particular product to achieve a goal. Usability evaluates ease of use with five quality attributes: 1) learnability, (2) efficiency, (3) memorability, (4) errors, and (5) satisfaction (Nielsen, 2012).

The learnability of a system refers to ease of use for a first-time user to perform basic tasks. Preece, Rogers and Sharp (2015) defined learnability as a novice user's initial understanding of a system and the attainment of maximum performance over time after repeated interaction. Sauro and Lewis (2012) indicated that learnability can be evaluated by how quickly a new user can become efficient with a system given that a more learnable system reduces the time it takes to complete tasks as the user spends more time interacting with the system.

When evaluating and discussing usability, it is "important to distinguish between the goals and practices of summative and formative usability" (Lewis, 2014, p. 679). Summative focuses on assessing how well a product meets its goals while formative is concerned with the iterative process of detecting usability problems during the product design and making recommendations for improvement prior to release (Albert & Tullis, 2013). Summative usability testing evaluates the functional software instead of wireframes and mockups and involves typical users of the product performing the task goals (Wood et al., 2021).

There is a general lack of research into usability testing in academia, particularly with regards to e-learning tools (Sandars, 2010; Sandars & Lafferty, 2010; Zaharias, 2009). Nuland et al. (2017) contended that commercial educational software industry and individual academic developers in the anatomical sciences have overlooked the added value of usability testing. Studies that evaluate e-learning systems for usability within the anatomical sciences domain are limited. An e-learning tool encompasses any interactive educational software computer program that mediates the learner's interaction with the educational material through an electronic interface that is hosted on the Internet or a local computer network (Nuland et al., 2017). Nuland et al. (2018) investigated the lack of attention towards usability testing among e-learning systems noting concern with e-learning technologies not achieving the intended impact on learning. The

majority of studies that assessed aspects of e-learning tool usability qualitatively assessed user perceptions of overall e-learning tool usability through questionnaires (Gould et al., 2008); O'Bryne et al., 2008; Hassigner et al., 2010; Lu et al., 2010; Doubleday et al., 2011; Guy et al., 2015). Rodrigues et al. (2019) stated the need to evaluate the learners' perceptions on the level of influence that the e-learning tools have and its affect with learning engagement and motivation.

Studies that evaluate user perceptions show students prefer cadaver dissection and textbooks over interactive 3D virtual anatomy tools (Azer & Eizenberg, 2007; Saltarelli et al., 2014). Saltarelli et al. (2014) noted that students' preference for the cadaver-lab over the anatomy simulation program may have been due to user perception factors of perceived usefulness and ease of use, which was not evaluated as part of the study. Nuland et al. (2018) and Gould et al. (2008) recognized that understanding usability factors may be essential in the successful use and wider adoption of the tools. Identifying learner frustration and anxiety during e-learning tool use is essential in ensuring e-learning tool success, and will require usability testing during all stages of an e-learning tool's life cycle (Nuland et al., 2017).

Gould et al. (2008) evaluated faculty and students' perceptions about the usability of a multimedia prototype for learning the limbic system in neuroanatomy to determine whether the multimedia design is effective or deficient in its usability properties. This study demonstrated the importance of integrating usability properties with principles of human learning during the instructional design process for multimedia products. Multimedia technologies were used for the program including QuickTime Virtual Reality Objects which gave a detailed view of the external features of a structure or region with 360-degree rotation, Hotspots with labeling which highlighted anatomical regions, and component dissection capability. The dissection feature

allowed the user to ‘‘strip’’ away structures to perform virtual dissection and reassembly tasks. Student participants were enrolled in graduate-level neuroscience courses. The faculty participants were required to be currently teaching or have previously taught professional-level neuroscience courses. The sixty-two study participants piloted the prototype and completed a usability questionnaire designed to measure two usability properties: program need and program applicability. While results showed high pedagogical value and applicability of the program in other courses, no further insight was given on the participants’ experience with the program.

Doubleday et al. (2011) conducted a usability test of an online virtual anatomy lab as part of the redesign of the original virtual lab to add for greater flexibility, interactive enhancements and richer content. The usability testing process evaluated efficiency, effectiveness, ease of use and overall user satisfaction using a variation of the Questionnaire for User Interaction Satisfaction short form (QUIS, 2010) to assess qualitative aspects of the resource used. The results indicated that the additional interactive features and richer content did not significantly take more time to complete and participants were better able to complete tasks better with the revised virtual lab. The results of this study suggest that even with increased level of complexity, the changes implemented improved participants’ navigational experience and more effective for users. Usability testing was used to determine whether increased content would impair navigation through the interface. The authors suggested the importance of conducting a usability study before and after implementable of a resource to help distinguish between a resource that fails to promote student learning and one that simply has a clunky or prohibitively complicated interface.

Hassinger et al.’s (2010) pilot study to assess the usability and perceived effectiveness of a 3D pelvic anatomy teaching module showed participant agreement of the strengths of the

model to be: ease of use, portability, efficiency, and clinical relevance. Results also show that 90% of the participants preferred this type of education to traditional methods. Despite these strengths, all participants commented that more anatomical detail was needed to improve its educational application for studying anatomy and to assist in the preparation for surgical cases. Findings from the pilot study were intended to be used for modification and further development of the simulator.

User Experience (UX) and User Engagement (UE)

Hassenzahl and Tractinsky (2006, p. 95) described user experience (UX) as "a consequence of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.) and the context (or the environment) within which the interaction occurs". UX has gained increasing recognition in HCI over the last decade to seek both the pragmatic (the usability aspects) and hedonic (sense of pleasure with use of the system) and aspects with use of the system (Hassenzahl, 2003). UX is concerned with the experience of an individual in contrast with the view of effectiveness, efficiency and satisfaction of a group of users. It is believed that the combination of pragmatic and hedonic qualities leads to positive or negative emotions and consequently influences product acceptance.

Increased emphasis on user experiences with technology demonstrates that systems must be not only usable, but also engaging (O'Brien et al., 2008). User engagement is considered essential with computer-mediated learning (Heflin et al., 2017; Webster & Ho, 1997) and successful use of interactive systems (Holdener et al., 2020; O'Brien & Toms, 2010). Lallemand et al. (2015) have recognized the need for a deeper understanding of the user experience. McArthy and Wright (2004) presented a framework that explained the felt, emotional quality of

experience, which served as a foundation for an aesthetic approach to seeing technology as an experience. Norman (2004) emphasized the importance of accounting for emotional response and aesthetics with interactive products. Hart et al. (2012) recognized the lack of a unifying model or theory that explained a judgment quality with use of interactive products and proposed a model used to evaluate the nature of user engagement. Seen as a subset of UX, which concentrates on judgment of product quality during interaction, the authors account for UE as a synthesis of judgment on usability, content, aesthetics, customization and brand, with the addition of interactivity in the form of affect, flow and presence (Hart et al., 2012).

O'Brien and Toms (2008) developed a conceptual framework based on their work on engagement on theories from aesthetics, flow, attributes of challenge and reward which defined user engagement as a quality of the user experience. They indicated the overlap between flow and engagement with differences existing such as the intrinsic motivation which significantly drives flow whereas engagement may occur even during suggested, mandatory, or necessary use of a system or application. Wiebe et al. (2014) compared engagement to flow using the Flow State Scale (FSS) and found that the user engagement scale (UES) by O'Brien and Tom (2010) and FSS were complementary in the video-game context, noting possible overlaps and lack of the UES to adequately assess flow. Perski et al. (2019) distinguished participants' state of engagement and flow and used the Flow State Scale components (loss of time or consciousness and balance between challenge and skill) to assess the digital behavior change interventions (DBCI) engagement scale's divergent validity.

Flow as a Measure of Engagement

Csikszentmihalyi (1985, p. 36) described flow as "the holistic sensation that people feel when they act with total involvement." The flow theory has been borrowed from psychology to

assess user experiences in computer-mediated environments. Csikzentmihaly (1975, 1997) identified nine specific dimensions necessary for flow experience to be achieved:

(1) clear and attainable goals,

(2) direct and immediate feedback,

(3) balance between activity challenge and individual skill,

(4) high degree of concentration,

(5) merging of action and awareness,

(6) temporary loss of time,

(7) temporary loss of self-consciousness,

(8) sense of personal control, and

(9) an autotelic, intrinsically rewarding experience.

Csikzentmihaly's work on flow theory has influenced a large number of research studies across various domains including psychology, sports, education, art, music, and gaming. Derived from flow theory, the concept of optimal experience been found to be robust and theoretically useful and has been validated in studies related to learning (Guo et al., 2016).

The state of flow and engagement have often been viewed as synonymous. Like flow, engagement has been evaluated for measuring optimal experience (Doherty & Doherty, 2018). If any activity or task is perceived to be interesting and not difficult enough to cause frustration, there's a high likelihood of total engagement when reaching a state of flow (Guo et al., 2016). Flow is conducive to learners feeling immersed in their learning engagement and influences subsequent usage behaviour (Goh & Yang 2021; Ghani, 1995). Goh and Yang (2021) examined the influence of flow to understand its effect on continuance to use a learning management system. The study found flow experience to positively relate to the continuance intention to use

the learning management systems and e-learning engagement to positively relate to flow experience.

Cooper (2010) identified studies of flow in technology-mediated learning environments with a positive relationship between flow and learning. The flow experience within a computer-mediated environment has been correlated to increased learning (Ghani, 2005), positive affect (Chen, 2000), computer use (Ghani & Deshpande, 1994) and exploratory behavior (Ghani, 1995). Flow has been used as a measure of student engagement with educational computer games (Inal & Cagiltay, 2007) and mobile learning games (Admiraal et al., 2011; Park et al., 2010). In flow, people feel involved in meaningful actions, maintain a sense of control and stay focused on a goal. Flow in the context of VR use indicates a positive association with intention to continue use and prolong sessions (Hassan et al., 2020).

Summary of What is Known and Unknown

The literature review provides a foundation for this study to further investigate how dimensions of UX--usability and engagement as measured by flow--influence use of 3D virtual anatomy tool to learn anatomy. Educators across medical institutions have a compelling need to seek innovative solutions to teaching human anatomy due to the declining hours dedicated to teaching anatomy and declining use of cadavers. A review of the literature reveals that while a variety of 3D virtual anatomy systems shows promising potential for learning (Codd & Choudhury, 2011), study results show predominant preference of students to favoring cadaver based learning and traditional methods over computer-mediated anatomy tools (Azer & Eizenberg, 2007; Saltarelli et al., 2014).

There is a general lack of investigation into UX factors which influence use of 3D virtual anatomy systems for medical students. Studies involving research with e-learning tools have

primarily drawn interest around measuring student learning gains and performance (Anand & Singel, 2017) with less attention to how the design of the tool affects the users' experience (Nuland et al., 2017).

User engagement is considered essential in the successful use of interactive systems (O'Brien & Toms, 2010; Perski et al., 2019). Flow as a measure of user engagement has been linked to higher user satisfaction and motivation with interactive technologies (Buil et al., 2018; Hung et al., 2012).

Chapter 3

Methodology

Overview

This chapter describes the study design, methods, and procedures. The addressable problem of the research was to investigate how ease of use and flow affect aspects of the students' experience with the use of a 3D virtual anatomy application.

The following research questions were investigated:

1. How do students rate their level of engagement as measured by flow based on their S FSS-2 scores?
2. How do students' perceptions of ease of use affect the flow experience based on the SUS and S FSS-2 scores?
3. What consequences of flow do students experience?
4. What aspects of the 3D virtual tool are distracting to performing the learning tasks?
5. How does flow help explain student satisfaction and motivation?
6. How do students perceive use of the tool to learn anatomy over cadaver-based dissection?

Study Design

A convergent mixed-method approach was used to investigate the user experience from the perspective of flow, as a measure of engagement, and ease of use in using a 3D virtual anatomy application on iPads and laptops. A convergent mixed-method design involves collecting the quantitative and qualitative data in parallel, analyzed separately for differences and similarities, then merged. Both quantitative and qualitative data each provide different insights

and merging the data allows the researcher to see the problem from multiple perspectives as shown in Figure 2 (Creswell & Clark, 2017, p. 186).

The convergent mixed-method is also useful when the researcher wants to compare quantitative statistical results with qualitative findings for a complete understanding of the research problem (Creswell & Clark, 2017). The procedures for implementing a convergent design are outlined in the procedural flowchart in Figure 3.

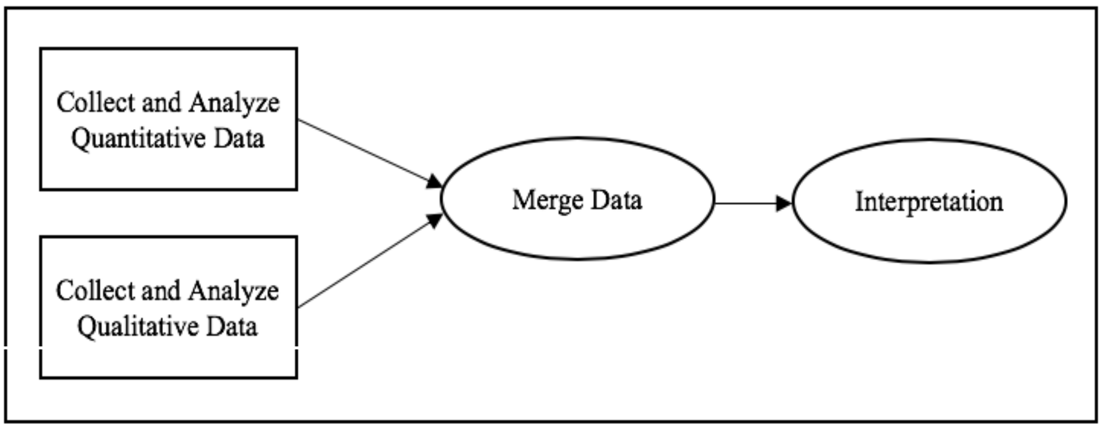


Figure 2. Convergent Data Merge

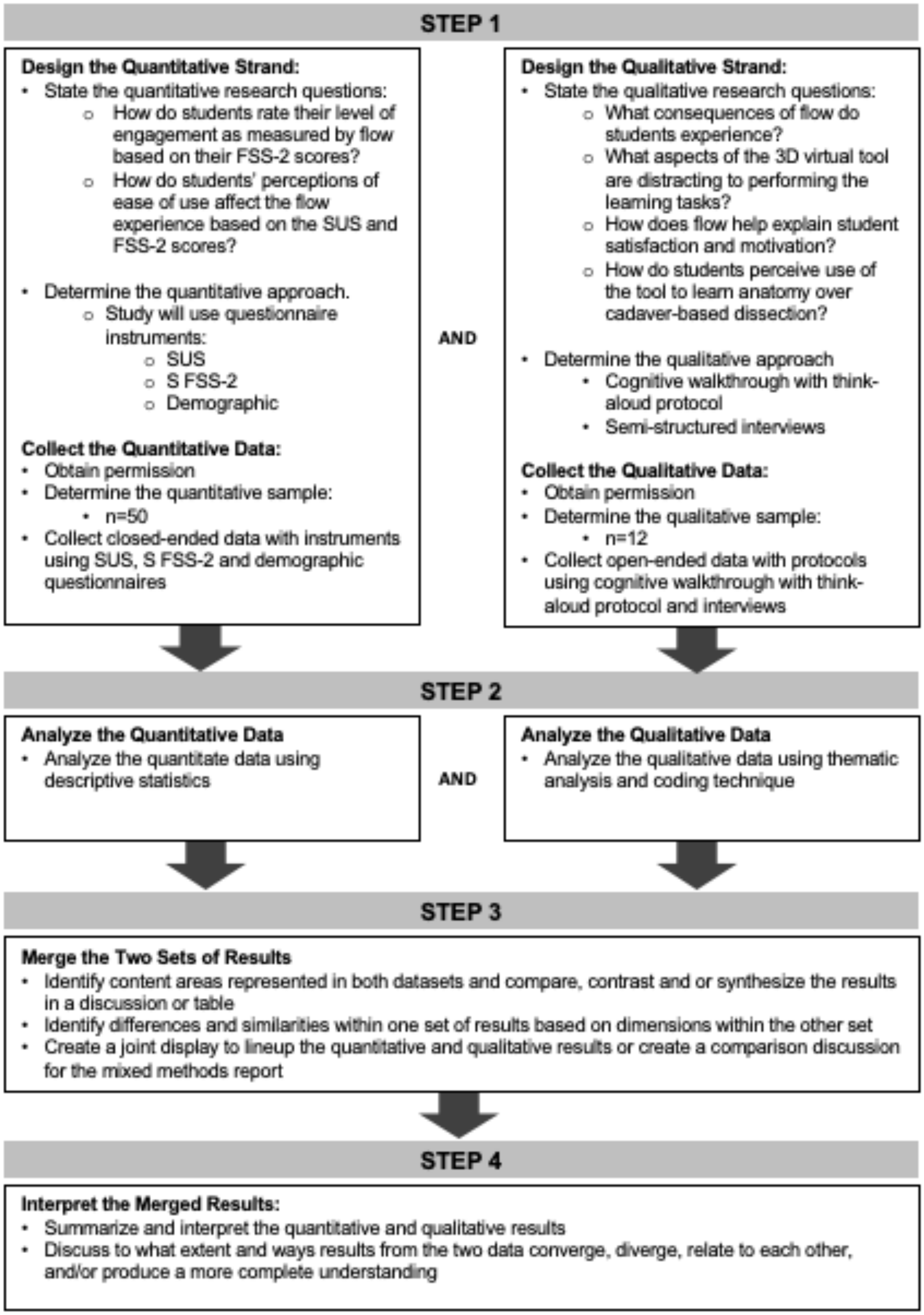


Figure 3. Flowchart of the Basic Procedures in Implementing a Convergent Mixed-Methods Design adapted from Creswell and Clark (2017).

The study was conducted according to the Convergent Mixed-Method design in Figure 3. The SUS scale and the S FSS-2 Scale were used to collect quantitative data at the conclusion of the participants' completion of the learning task (See Appendix C) in the independent session. Semi-structured interviews were conducted with a subset of participants who have completed the surveys in the independent session. The interview session included a CW set of tasks to gather qualitative data on the user experience with the anatomy tool. The TAP technique was integrated with the CW to encourage participants to verbally convey their thoughts, actions and feelings while performing the learning task.

Study Steps

The study was conducted as follows.

1. The technology resources needed (See Appendix D) to conduct the study were acquired, tested, and prepared. Hardware, software, and storage needed were verified to ensure security requirements were met (encryption, authentication, logging and audit capabilities enabled).
2. The dissertation committee approved the study after successfully defending the dissertation proposal. The IRB application was submitted to the College of Computing and Engineering at Nova Southeastern University, Ft. Lauderdale, FL and approved on October 16, 2020 (See Appendix E). The IRB application for Florida International University was submitted and approved on January 6, 2021 (See Appendix F).
3. Materials for the study were created and prepared:
    - Recruitment flyer - QR code was incorporated in the recruitment flyer for convenient email reply back to the researcher (See Appendix G)

- Email response template for individuals seeking information related to the study (See Appendix H)
- Two Articulate Rise modules (Study Overview, Getting Started with the Independent Session) (See Appendix I and Appendix J)
- Invitation to participate in the Subsequent Session email template (See Appendix K)
- Completion of the Independent Session email template (See Appendix L)
- Completion of the Subsequent Session email template (See Appendix M)
- Subsequent Session dissection activity participant instruction (See Appendix N)
- The researcher's script on conducting the subsequent session

4. The recruitment process was initiated in February 2021. Printed flyers were posted in the public areas of the college and a recruitment email was distributed to all the medical student cohort listservs.
5. Interested participants responded using the FIU email system to indicate their interest. Participants were sent information related to the study and Informed Consent form. Participants submitted signed Informed Consent forms and returned them in email. They received additional instructions using the online Articulate module on how to proceed with the study and perform the independent session (See Appendix O).
6. Participants who completed the independent session and performed the heart dissection activity completed four anonymous Qualtrics surveys: Demographics (Appendix P), Attestation of Completion (Appendix Q), SUS, and S FSS-2. Participants who completed the independent session and submitted all four surveys received the $20 Amazon gift card electronically using their FIU email within five days of completion.

7. Participants who completed the independent session were qualified to participate in the subsequent session, “Cognitive Walkthrough and Interview.” Interested participants received additional information via FIU email on information regarding the subsequent session and provided procedure steps using the online Articulate module. The subsequent session was scheduled based on mutually agreed dates and time.
8. The CW and interview session were conducted over Zoom and participants used either their iPads or laptops to perform the abdominal dissection. Participants shared their screen with the researcher using the Zoom share functionality to enable the researcher observation during the activity. The interview segment followed the completion of the CW in the same meeting. Participants who completed the subsequent session and submitted all four surveys received the $20 Amazon gift card electronically using their FIU email within five days of completion.
9. The de-identified audio portion of the interview segment from the Zoom recording was submitted to Rev (www. rev.com), a secure online transcription service company. The interviews were transcribed and used for the data analysis.

The researcher’s analytical process followed the convergent mixed method (Creswell & Clark, 2017) and Saldana’s (2016) coding cycles and thematic analysis. A comprehensive report of the analytical procedures and findings are provided in Chapter 4.

Participants, Recruitment and Selection

Convenience sampling, a non-probability sampling method, was used in the study for purposes of availability and accessibility to a target population, medical students. The researcher’s goal was to recruit a target participant and sample size of 50 from among a total population of 460 medical students. The selection criteria for participants were students who

have completed the Structure of the Human Body course. In addition, a goal of 12 participants from the total participant sample were to be selected for a follow-up interview which included the CW and TAP observation activity. The selection criteria for the 12 participants were as follows:

- Students who have completed the SUS and S FSS-2 surveys.
- Students whose scores indicate inconsistency with ease of use and flow state.
- Students whose scores indicate ease of use is consistent with flow state.
- Students who have completed the Structure of the Human Body course.

The selection criteria for the interviews provided a deeper understanding of the relationship of ease of use with flow state (engagement) and the students' account of their experience through the interview process. The completion of the Structure of the Human Body course is relevant due to the anatomy systems and learning tasks selected for the study. The course instructor of the Human Anatomy was consulted on the selected learning objectives for the dissection activity in the study. The learning objectives were selected from the course syllabus.

Recruitment and study sessions were conducted from February to April 2021. Due to factors impacting time commitment (cohort transitions during March to April and graduation in April) some participants were unable to proceed with the study. Table 1 summarizes the recruitment results.

Table 1

Recruitment Responses

Number of interested responses to the recruitment flyers	Number of received participant Informed Consent form	Number of participants who completed the Independent Session	Number of participants who completed the Subsequent Session
38	26	17	10

Environment and Technology Setup

3D Virtual Anatomy

The Complete Anatomy application (see Figure 4 and Figure 5), created by 3D4Medical, LLC, was first released in 2016 and became a publishing platform for interactive anatomy course in the spring of 2019. Complete Anatomy content images and courses are designed with leading anatomists worldwide in areas such as histology, radiology, cadaveric imagery, clinical correlates, and physiology. Complete Anatomy, version 6.1, is a highly interactive 3D visualization anatomy software. With Complete Anatomy, users can manipulate and explore human anatomy, perform virtual dissections, collaborate and share content, annotate anatomical features, review lessons, and plan procedures. Students can choose from thousands of anatomy images in the Complete Anatomy database. Medical students are provided iPads and touch screen laptops as part of curriculum with Complete Anatomy installed. The iPad and laptops with Complete Anatomy are used as education technology resources in the anatomy course.

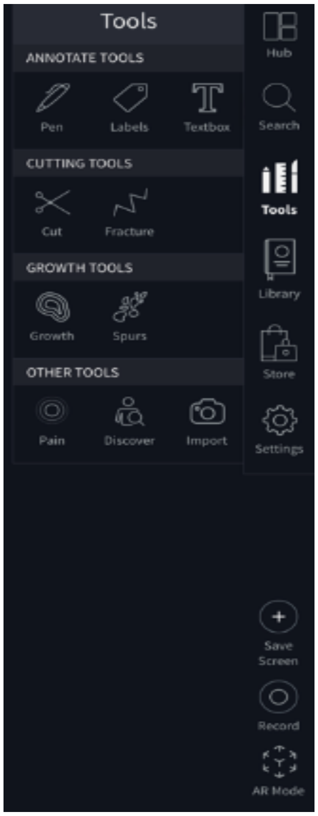


Figure 4. Complete Anatomy with Tools Menu

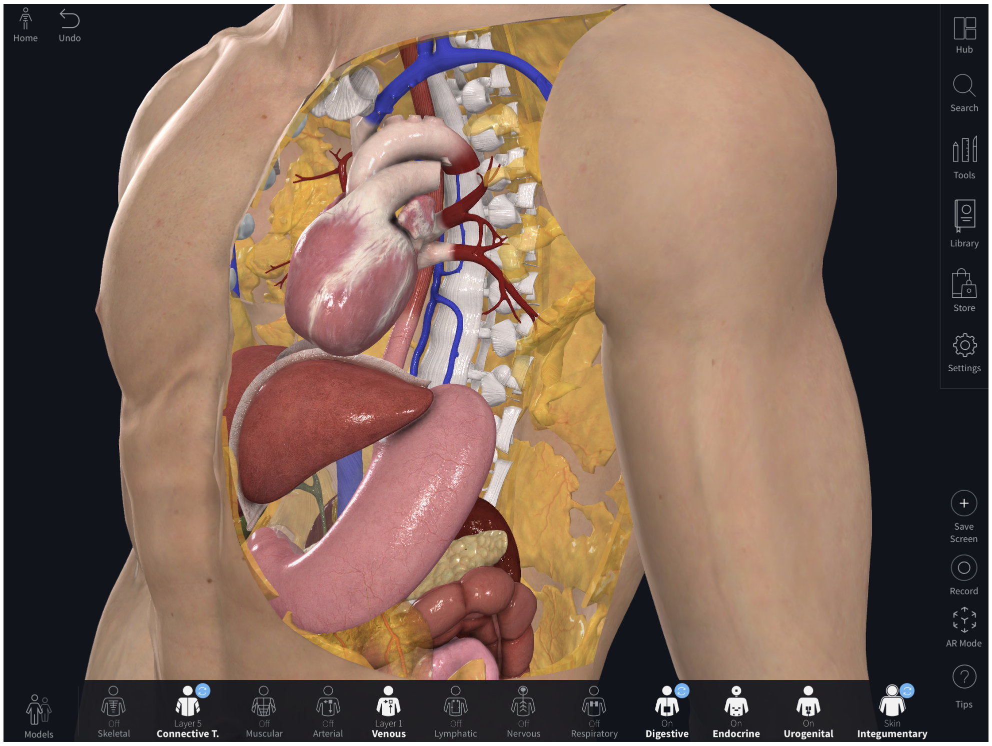


Figure 5. Complete Anatomy Zoomed-in

Setting

The procedure for the setting was designed and facilitated with maximum consideration for COVID-19 safety protocols based on FIU COVID-19 standards and practices. Interactions and communications with the participants were conducted entirely online and remotely. Communications were conducted over the FIU email system with options for participants to contact the researcher by phone. Trainings and surveys were available online and one-on-one sessions with the researcher was conducted over Zoom. Participants had the flexibility of completing the independent session on their own time and location with Internet access. The researcher conducted the subsequent session both at home and the office behind closed doors to minimize and prevent disruptions.

Procedures

The study was conducted in the spring of 2021 (February to April) when training, virtual dissection learning tasks, survey questions, CW with TAP observation, and interview sessions were conducted as summarized in the *Procedure Diagram* (see Figure 6).

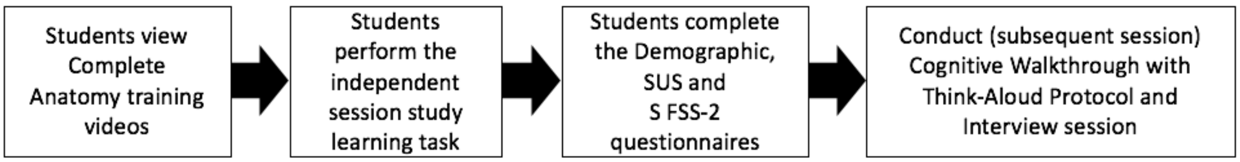


Figure 6. Procedure Diagram

While all medical students have access to Complete Anatomy on their college-issued iPads and laptops, Complete Anatomy is still a novel application recently made available to students in the fall of 2019. To provide a baseline understanding on how to use the app, participants were asked to view three online short instructional videos from Complete Anatomy which included searching and accessing the anatomy images, dissection tools, and navigating the anatomy models (see Table 2).

Table 2

Complete Anatomy Training Videos

Title	URL	Duration	Description
Search	https://3d4medical.com/support/complete-anatomy/search	0:37 minutes	● Access search ● Search results

Table 2 Continued

Title	URL	Duration	Description
Cut and Dissect	https://3d4medical.com/support/complete-anatomy/cut-tool	1:06 minutes	● Access Cut ● Using the cut tool ● Cut multiple structures ● Cut options ● Cut between ● Cut hole ● Clear cuts
Navigating the Model	https://3d4medical.com/support/complete-anatomy/navigating-the-model	1:06 minutes	● Rotating ● Zooming ● Panning ● Selecting a structure

After reviewing the tutorials, participants were instructed to perform two virtual dissection learning tasks which were derived from learning objectives in the anatomy course. The independent session was performed on participants' own time and location.

Learning Task (Independent Session)

In Complete Anatomy, perform a dissection of the heart using the cut tools. Select multiple layers for depth of cut and cut line option. Use the pen tool to label the anatomical parts for items a and b.

a) Recognize the three-dimensional relationship of the heart chambers.

b) Distinguish between aortic, pulmonary, mitral, and tricuspid valves.

Participants completed the following online Qualtrics surveys after completing the Independent Session learning task: Demographics, Attestation of Completion of the Independent Session,

SUS, and S FSS-2. Each participant total estimated study time for completion is outlined in Appendix R.

Participants who completed the independent session were invited to participate in the subsequent session, the CW and Interview. The subsequent session involved two parts: virtual dissection activity using CW and TAP and interview segment. Individuals who volunteered for the subsequent session were scheduled for a Zoom meeting at mutually agreed date and time. Prior to the Zoom meeting, participants were emailed the Dissection Activity document containing the CW task goal and pre-defined task steps. The document was used to guide the participant during the CW segment.

Learning Task (Subsequent Session)

In Complete Anatomy, perform a dissection of the abdominal region using the cut tools. Select multiple layers for depth of cut and cut line option. Use the pen tool to label the anatomical parts.

a) Identify the three-dimensional relationship between the stomach, small intestine, pancreas, liver, and gallbladder.

The researcher started the CW segment using a script to thank the participant, remind the participant the volunteer nature of the session and provide verbal instructions on completing the activity. The researcher used the CW evaluator's guide (See Appendix S) to take notes during the observation of the dissection activity. The interview segment followed immediately after the CW. The interview was guided by the interview questions (See Appendix T). The researcher took notes during the interview.

Data Collection and Instrumentation–Multiple Sources

The researcher's intent was to triangulate the results from various data sources collected from four independent sources using validated instruments. Triangulating different sources of data enables the researcher to validate resulting conclusions when they are supported by multiple forms of evidence as well as gain a more in-depth nuanced understanding of the findings (Creswell & Clark, 2017).

Surveys

Surveys are a common method for collecting quantitative data and provide efficient data collection and ease of analysis (Seliger & Shohamy, 1989). Close-ended questionnaires were used to facilitate the SUS and S FSS-2 surveys. The SUS and S FSS-2 were administered to collect quantitative data after the learning activity was completed using the 3D Virtual anatomy tool. The SUS assessed student perceptions on the usability of the 3D Virtual anatomy tool. The S FSS-2 assessed student engagement as measured by flow. Demographic information was collected to develop participant profile.

The Systems Usability Scale (SUS) (Brooke, 1996) assessed two usability attributes, learnability and ease of use, with the 3D virtual anatomy application. The SUS has been used extensively in evaluating a wide variety of products and services and testing user interfaces. The SUS consists of ten items. Participants were asked to score each question using a 5-point Likert scale that ranges from Strongly Disagree to Strongly Agree.

The flow experience was measured based on the Short Flow State Scale-2 (S FSS-2), developed by Jackson et al. (2010) and applied for use among student participants in a 3D learning experience (Bressler & Bodzin, 2013). The S FSS-2 is meant to be a holistic measure of a user's flow state. While this scale was developed and validated for measurement of sports-

related activity, it has been used to measure a broad definition of flow in technology-mediated learning experience including augmented reality (Bressler & Bodzin, 2013), and video games (Ma & Williams, 2011; Weibe et al., 2014). The scale measures nine dimensions of the flow experience as outlined by Csikszentmihalyi (1990). The scale consists of nine items and participants were asked to score each item using a 5-point Likert scale that range from Strongly Disagree to Strongly Agree.

Demographic information was collected to develop participant profile using questionnaires. The demographic questionnaire included gender, age group, and cohort level at the time the participant completed the study.

Cognitive Walkthroughs with Think-Aloud Protocol

CW with TAP were used to collect qualitative data (participant's performance and responses and reactions while performing tasks). These techniques were used to gain deeper insight on the student experience and to corroborate and expand on evidence gathered from the quantitative surveys. The CW is a usability evaluation method (Mahatody et al., 2010) with a predefined set of tasks that the participants perform. The CW is based on the premise that users often learn how to use a product through a process of exploration, not through formal training courses (Polson & Lewis, 1990). The CW facilitated the analysis of a user interface by simulating a step-by-step user behavior for a predefined set of tasks. The researcher reflected on the following questions for each task the participant completed based on Wharton et al.'s (1994) set of evaluation questions.

- Will the user try to achieve the right effect?
- Will the user notice that the correct action is available?
- Will the user associate the correct action with the desired effect?

- If the correct action is performed, will the user see that progress is being made towards the solution of the task?

The CW task goal was to identify and label the three-dimensional relationship between small intestine and pancreas, liver, and gallbladder. The predefined task sequence is as follows:

- Open the Complete Anatomy application
- Go to the Content Library
- Select the Search icon
- Place cursor on the search field and type "abdominal dissection"
- Select "abdominal dissection" from the list of anatomical modes
- Size and rotate the model as desired
- Select the Tools menu
- Select the Cut tool
- Select single layer for depth of cut
- Choose the "Cut line" from the Cut options
- Perform the dissection to examine the anatomical parts
- Select Done
- Size and rotate the model as desired
- Select the Pen tool and label the anatomical parts
- Select Done

In addition to the evaluation questions, the researcher recorded success stories, failure stories, design suggestions, comments about the tasks, and other information that was important. The researcher recorded the step in the sequence where an issue occurs using the researcher's own words to describe the problem. If the participant stopped thinking aloud, the researcher

avoided using prompts which unduly influence cognitive processing (Greene, Robertson, & Croker Costa, 2011) and instead use simple phrases to spur participant to continue such as 'tell me what you are thinking,' 'go on,' or 'tell me more." The TAP technique identified problems that exists as the user navigates through the interface while verbalizing their thoughts (Alhadreti & Mayhew, 2017). In the think aloud process, users were encouraged to express their thoughts, actions, and feelings while interacting with the interface.

The integration of the TAP technique CW helped identify potential usability problems with interactive systems (Barnum, 2011). The CW with TAP was conducted first, followed by the interview segment. CW and one-on-one interviews were conducted with ten participants who completed the SUS and S FSS-2 surveys in the independent session. Guest et al. (2006) proposed that 12 interviews of a homogenous group is sufficient to reach saturation, a point at which the data collection process no longer offers any new or relevant insights. The researcher conducted the CW with TAP and interview session over Zoom with recording enabled to capture the interview dialogue to reliability work with participants' spoken words during the transcription process. Preserving the participants' words in the recording allows the researcher to refer to the source for further clarity or check on inaccuracies that may occur in the transcript.

Semi-structured Interviews

A fundamental goal of interviewing is an interest in understanding the lived experience of individuals and the meaning they make of that experience (Seidman, 2006). Semi-structured interviews with open-ended questions are commonly used in qualitative research. This method consists of a dialogue between researcher and participant to explore participant thoughts, feelings and beliefs about a particular topic (DeJonckheere & Vaughn, 2019). Semi-structured interviews

were conducted to obtain qualitative data on each participant's experience using Complete Anatomy.

The semi-structured interview guide provides a clear set of instructions for interviewers and can provide reliable, comparable qualitative data (Jamshed, 2014). Semi-structured interviews were conducted to obtain qualitative data on each participant's experience using Complete Anatomy. The following guide of questions facilitated the interview:

1. **What consequences of flow do students experience?**
    - Please describe your experience in performing the learning tasks using Complete Anatomy.
2. **What aspects of the 3D virtual tool are distracting to performing the learning tasks?**
    - How intuitive or cumbersome was Complete Anatomy and why?
    - Please describe any part of your experience that may have been frustrating.
3. **How does flow help explain student satisfaction and motivation?**
    - Please describe how satisfied you were with your experience in using Complete Anatomy in performing your learning tasks.
    - How did Complete Anatomy motivate you to want to learn anatomy?
4. **How do students perceive use of the tool to learn anatomy over cadaver-based dissection?**
    - What are your perceptions of Complete Anatomy as an alternative anatomy dissection tool to human cadavers?

An additional question was introduced to directly ask participants about level of flow or 'in the zone' as part of question 1. This modification was determined after the first four

participants were not mentioning experience related to flow. The researcher consulted with her dissertation advisor before proceeding.

Data Organization and Analysis

The researcher exported Qualtrics surveys as Microsoft Excel files to cleanup (e.g., removing unnecessary columns generated by Qualtrics as metadata and better readability of columns and data) and prepare for scoring assignment and importing into IBM SPSS for further analysis. SPSS is a statistical program for the Social Sciences (SPSS) and used to record and compute the quantitative data. Quantitative analysis includes descriptive statistics (Terrell, 2012) which was used to summarize the demographic survey, SUS and S FSS-2 results.

Transcription

Transcription is the process of documenting interview data into written words spoken verbatim by the participant to be used for coding and analysis. Transcribing interviews can be time consuming and a 90-minute recording can take between 4-6 hours to transcribe (Seidman, 2013). For efficiency, a reliable and accurate online transcription service, Rev, was used to convert audio from the interview into a text-based file. The researcher performed an iterative process of reviewing and proofreading the transcript to improve readability. The transcripts included the following information:

- Title of the research study
- Names of the interviewer and participant ID
- Date and time of the interview
- Location of the interview
- Speaker designation

Qualitative Data

All observation notes from the CW and interview segments were electronically captured in Microsoft Word using the respective documents, CW evaluator's guide and Interview Questions guide. The researcher performed cleanup and refining of observation notes using the Zoom recordings and transcripts of the interviews. NVivo was used to further organize and analyze the interview transcripts. The researcher determined and configured the appropriate data file and coding file structure and naming convention. Case classifications were defined to provide demographic details about the participants. Classifications in NVivo record descriptive information about the files and cases in a project. Once NVivo was prepared, transcripts were imported for coding, memoing, categorizing, and thematic analysis. NVivo assisted with easy tracking and organization of codes, labels, memos, annotations, and visual mapping of codes and themes developed.

Coding Technique and Thematic Analysis

In qualitative analysis, coding serves as a link between data collection and explanation of their meaning (Charmaz, 2001). A code is a construct generated by the researcher that symbolizes the data (Vogt et al., 2014) that is later interpreted for purposes of pattern detection, categorization, theory building, and analysis. Coding enables the organization and grouping of similarly coded data into categories or "families" because they share some characteristic which formulates the beginning of a pattern (Saldana, 2016). Qualitative data collected from interviews, CW and TAP method were analyzed using coding technique and thematic analysis.

First Cycle Coding

The first cycle coding is a preliminary coding method that serves to organize the raw qualitative data. Multiple coding methods can be applied and overlap during the first cycle

coding process. The first cycle coding approach used initial coding, in vivo, and descriptive methods. Initial coding separates qualitative data into distinct parts, closely examines them, and looks for similarities and differences (Strauss & Corbin, 1998, p. 102). Initial coding is an open-ended approach in which the researcher codes for “first impression” words or phrases in response to data the researcher finds striking, surprising, or engaging (Creswell, 2007). During this process, codes are considered tentative until further iterative cycles are conducted.

In vivo coding has been labeled “literal coding,” or “verbatim coding,” which is drawn from the word or phrase that participants expressed or uttered themselves (Saldana, 2016). Descriptive coding summarizes in a word or short phrase the basic topic of a passage of qualitative data that serves to identify the topic itself rather than an abbreviation of it (Tesch, 1990). Descriptive coding leads primarily to a categorized inventory or summary of the data’s contents. It is essential groundwork for second cycle coding and further analysis and interpretation (Wolcott, 1994).

During the first cycle coding, the researcher performed initial read-through of the interview transcripts for familiarity of the data then proceeded with performing the initial coding and memoing in Word format (see Figure 7). The process of coding and memoing involved line by line review, marking or selecting words or phrases that were considered relevant or interesting and assigned broad codes and labels to represent or note its meaning. The interview transcripts were shared with her dissertation advisor for quality control for further coding review, memoing, and comments.

The codes were reviewed and analyzed for patterns and emerging themes. As each line of the transcript was reviewed, the researcher continued to jot notes, labels, assigned categories to excerpts phrases, search for connecting threads and assess connections between categories to

draw out themes (Seidman, 2013). The coding process was iterative with first cycle coding methods and between first and second cycle coding (see Figure 7). The research questions were reflected upon for each iteration of participant narrative review. This process helped frame and focus the lens from which the researcher can better understand and interpret the participant's experience.

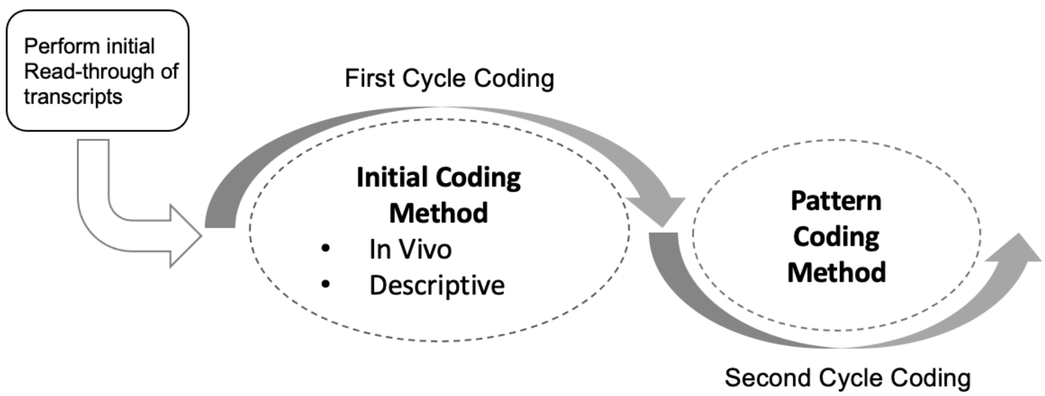


Figure 7. Coding Cycles

A theme is an outcome of coding, categorization, or analytic reflection and brings meaning to a recurring experience (Saldana, 2015). The researcher searched for themes by looking for qualities such as repeating ideas, participant's terms, metaphors and analogies, similarities and differences of participant expressions, and connectors (such as "because," "since," "then") (Ryan & Bernard, 2003). Computer Assisted Qualitative Data Analysis Software (CAQDAS) program, NVivo by QSR International, is used to store, categorize, manage and analyze qualitative data (Wong, 2008). NVivo helps minimize errors with its search capability yielding more accurate results when working with large datasets compared with manual human effort. NVivo software was also used to code transcripts for themes and find insights in the qualitative data from interviews, CW and think-aloud process.

Second Cycle Coding

The primary goal during second cycle coding is to develop a sense of categorical, thematic, conceptual, or theoretical organization from the set of first cycle codes (Saldana, 2016). The researcher reorganized and reconfigured the first cycle codes and developed a smaller and more select list of broader categories and themes. The researcher generated 421 codes during the first cycle coding and then recoded and categorized according to similarities during the second cycle coding which resulted in 15 initial categories. The emerging themes were then drawn from the final list of categories. Table 3 displays the initial categories and emergent themes development.

Table 3

Emergent Themes Development

Initial Categories	Emergent Themes
Ease of Use	Ease of Use
Efficiency	Efficiency
Learnability	Learnability
Focus	Focus/In the Zone
Engagement	Focus/In the Zone
Recognition	Learnability
User Control	User Satisfaction
Technical Performance Issue	UI – Technical
Preferences	User Satisfaction
Training Need	Learnability
Satisfaction	User Satisfaction
Memorability	Learnability
Interaction	UI – Interactive
Visualization	Visuospatial
CA vs. Cadaver	CA vs. Cadaver

Scoring and Interpreting the System Usability Scale

Brooke (1996) developed the System Usability Scale (SUS) as a measure of usability and can be applied with a wide range of technologies (Brooke, 2013). The survey consists of ten

questions each with a five-point Likert response continuum from Strongly agree to Strongly disagree. The SUS provides a score from 0 to 100 and considered percentile ranking, not percentages. The average SUS score is 68; a score under 68 considers the particular technology under evaluation as having usability problems (Sauro, 2011).

To calculate the raw SUS item scores into an overall SUS score (Sauro, 2011):

- For odd-numbered items, subtract one from the user response.
- For even-numbered items, subtract the user responses from 5. This scales all values from 0 to 4 (with four being the most positive response).
- Add up the converted responses for each user and multiply that total by 2.5 (to convert the range of possible values from 0 to 100 instead of from 0 to 40).

Scoring and Interpreting the Short Flow State Scale-2

The 9-item Short Flow State Scale-2 (S FSS-2) is an abbreviation of the 36-item Long Flow State Scale-2 (FSS-2) (Jackson et al., 2008). The scale measures flow elements outlined by Csikszentmihalyi (1990). Jackson et al., (2008) and Martin and Jackson (2008) recognized the need for an abbreviated shorter version of the FSS-2 for practical purposes where participants may be reluctant to answer a 36-item scale. There are nine dimensions in the Short Flow State Scale-2 (S FSS-2) and one item represents each dimension. The S FSS-2 provides a holistic concept of flow as one coherent experience that is drawn from the nine flow dimensions (Jackson et al., 2008). As such, this study used the nine dimensions collectively as a single measure of overall individual's flow state. The general recommendation is to sum the nine items together and then divide by nine to obtain a S FSS-2 score. In the event of a missing item score, the average of the items with the response will be calculated. If there are more than two missing response on the scale, then the validity of the scale responses is questionable.

The lowest possible score on the Short Flow scales is 1, with the highest being 5. Each respondent completing the scale is asked to indicate the extent of their agreement with each item ranging from 1 (strongly disagree) to 5 (strongly agree). The score is interpreted against this range with the lower item average values indicating a strong degree of disagreement and higher item average values indicating a strong degree of agreement. Low agreement with statements indicative of a flow characteristic is suggestive that the person's experience was not substantively "flow-like". Conversely, a strong degree of agreement of item statements indicates that the individual was undergoing a "flow-like" experience (Jackson & Eklund, 2004).

Interpreting the Cognitive Walkthrough with Think-Aloud Protocol

The CW method evaluates each step needed perform a task and finds mismatches between the user's and designer's conceptualization of a task either by poor labeling choices in the menu or buttons and lack of system feedback with actions taken by the user (Wharton et al., 1994). CW attempts to uncover design errors that would impede learning by exploration. The researcher assessed the usability problems in the context of success and failures identified for each action step. A failure occurs when the investigator answers "no" to any of the questions for each correct action which suggests a possible usability problem. The coding and thematic analysis from the TAP technique will contribute towards the success and failure stories explanation in CW process.

Quality Control

Reliability and Validity

In quantitative and qualitative research, the researcher is concerned about matters of reliability and validity in different ways. In quantitative research, reliability means that score results from participants are consistent and stable over time (replicable), while validity means

that score results are accurate and measuring what they intend to measure (e.g., the constructs). The SUS is considered highly reliable and valid (Lewis, 2014; Sauro, 2011) with the reliability coefficient over .90 (Brooke, 2013; Sauro, 2011). Even at very small sample sizes, the SUS can still generate reliable results (Sauro, 2011). SUS has been shown to distinguish between unusable and usable systems with high concurrent validity (Sauro, 2011). The Flow State Scale (Jackson & Ecklund, 2002) has been formally tested for reliability and validity across multiple domains. Martin et al. (2006) showed good internal consistency with a coefficient of .82 for the S FSS-2.

Qualitative researchers emphasize accuracy, transferability and credibility over the quantitative concept of replicability (Creswell & Clark, 2017; Golafshani, 2003). While validity differs between quantitative and qualitative research, it provides the function of verifying the data quality, the results, and interpretation of the data results (Creswell & Clark, 2017). There is more of a focus of validity in qualitative research than reliability. Alternative terms have been used for qualitative validity, such trustworthiness or authenticity (Lincoln & Guba, 1985).

Determining qualitative validity means assessing whether the information obtained through the qualitative data collection is accurate, such as examining the extent to which the information is credible, transferable, dependable, and confirmable (Lincoln & Guba, 1985). The researcher employed the triangulation strategy to determine qualitative validity using multiple sources to build evidence of code and themes during analysis (Creswell & Clark, 2017).

Researcher and Ethical Considerations and IRB

The researcher ensured that no individual suffered any adverse consequences related to the data collection process and procedure. Moreover, the researcher was attentive to maximizing positive outcomes of the research process. The researcher ensured confidentiality, anonymity

and safety of participants data using secure document storage platforms, survey systems and process. The researcher completed the Collaborative Institutional Training Initiative (CITI) basic/refresher course for the Human Subjects Research August 14, 2020. FIU and NSU's Institutional Review Board (IRB) approval were obtained as part of a requirement with studies involving human subjects (Creswell & Clark, 2017). The researcher submitted the IRB application to both Florida International University and Nova Southeastern University.

Participants' privacy was protected through the assignment of a random three-digit participant ID that participants used for completion of the surveys. The transcribed audio files did not contain identifiers and was labeled with participant ID. All files were stored on encrypted storage at all times and accessed from researcher's secure laptop. Email system (Microsoft O365) used between participants and researcher is a secure platform with storage and transmission encryption.

Resources

Resources required to conduct and facilitate the study included hardware, software, Internet connectivity, transcription services, and Amazon gift cards for participation honorarium. The list of resources is outlined in Table 4. Transcription services and Amazon gift cards were researcher funded. Participants are issued laptops and touchscreen Lenovo laptops and iPads as part of their educational technology resource in the medical school curriculum. The Complete Anatomy app is installed on both devices.

Table 4

Resource List

Hardware	**Users**
Laptop with webcam and mic	Researcher and Participants
iPad	Researcher and Participants
Software and Services	
NVivo 1.5	Researcher

Table 4 Continued

Microsoft Office Suite	Researcher and Participants
3D4Medical Complete Anatomy	Researcher and Participants
Qualtrics	Researcher
Transcription (Rev)	Researcher
Articulate	Researcher
Internet Connectivity	Researcher and Participants
Instruments	
The Flow Manual	Researcher
Flow Remote Online Survey Licenses	Researcher

Summary

Chapter three describes the methods, study design, participant selection strategy, and data collection and analysis plan. Data analysis methods were outlined for the quantitative and qualitative data. Survey instrument scoring and interpretation were discussed for the System Usability Scale (SUS) and the Short Flow State Scale (S FSS-2). Qualitative data coding technique and thematic analysis were described. Different approaches to quantitative and qualitative research reliability and validity were discussed offering strategies to enhance data reliability and validity in both methods.

Chapter 4

Results

Overview

This chapter presents the results and analysis of investigating the user experience with the use of 3D virtual anatomy application among medical student participants. This study applied a convergent mixed-method approach to investigate the user experience from the perspective of flow, as a measure of engagement, and ease of use with using a 3D virtual anatomy application. The findings triangulate the quantitative and qualitative data to answer the research questions. The quantitative data provided SUS and flow scores. The qualitative data provided deeper insight into the SUS and flow scores and for a more comprehensive understanding of participants' user experience.

A process of coding, memoing, and codifying was applied to the qualitative data collected from CW with TAP and interview sessions. First and second cycle coding methods were followed to guide the researcher through the iterative steps of initial coding to developing themes drawn from coding patterns. This chapter provides an in-depth discussion, description, analysis, and interpretation of the quantitative and qualitative data.

Data Analysis–Process

The data collection strategy described in Chapter 3 is outlined here to summarize the data collection process and provide the in-depth analysis performed. The study used survey instruments, observations of CW and think-aloud sessions, and interview sessions.

1. Survey data–Surveys were created and distributed through Qualtrics for:
    - Participant demographic information

- Attestation of Completion of the Virtual Dissection Learning Task
- System Usability Scale (SUS)
- Short Flow State Scale-2 (S FSS-2)

2. Observation data using CW and TAP–The CW was conducted remotely over Zoom. The 'Cognitive Walkthrough Task and Evaluator's Documentation Guide' aided the researcher with conducting the CW session. The guide contained the predefined steps the participants were instructed to perform with corresponding evaluator questions for each task item to assess usability. The TAP integrated with the CW facilitated participant's verbal expressions of their thought process. Task completion results and observation notes were collected during CW sessions.
3. Interview data–Participants responded to interview questions on their experience with using the 3D virtual anatomy application to perform the dissection learning tasks. Zoom audio recording was used for professional transcription and the transcripts were used for the analysis.

Data collection was conducted from February 2021 to April 2021. Following the convergent mixed-method framework, both quantitative and qualitative data were collected during the same time frame. After the completion of the data collection, the two data types were analyzed independently, then merged the independent findings to interpret the results together (Creswell & Pablo-Clark, 2011). The findings are presented as follows:

1. Participant Demographics and Attestations
2. SUS Data
3. S FSS-2 Data
4. Comparison of SUS and S FSS -2 Data Analysis

5. Cognitive Walkthrough and Think-Aloud Protocol Analysis
6. Semi-Structured Interview Data
7. Quantitative and Qualitative Data Merge and Analysis

Data Analysis Results

Participant Demographics and Attestations

Participant demographic information was collected using Qualtrics survey. The data captured included age, gender, age group, and cohort level. Participant data (N = 17) was collected using a Qualtrics survey. The participants consisted of 10 females and seven males. There were 11 participants in the 18-24 age group and six in the 25-34 group. Participants were represented from each cohort levels M1-M4 (Medical student year 1-Medical student year 4): M1=6; M2=5; M3=3; M4=3.

Attestation of completion was completed for participants who participated in the Independent Session. Participant attestations on completion of the first session (N = 17) was collected using Qualtrics survey. All participants attested to completing the Independent Session.

System Usability Scale Data

Participants' perceived ease of use was measured using the System Usability Scale survey by John Brooke (1996), an established usability measurement tool. The SUS survey was distributed to participants using Qualtrics. Participants completed the SUS survey following completion of the virtual dissection as part of the Independent Session. All 17 participants completed the SUS survey with no missing values. The SUS survey data were exported from Qualtrics into Excel format. The researcher performed calculations and analysis of the raw SUS scores using Sauro's (2011) SUS Calculator Excel workbook. The SUS Calculator contains a

series of spreadsheets with predefined formulas to automate analysis from scoring to reporting and interpretating the data.

Across thousands of individual SUS scores and hundreds of global systems, the average SUS score is approximately 68 and differs by a few points by interface type (Sauro 2011). A score under 68 considers the particular technology under evaluation as having usability problems. The study resulted in a mean SUS score of 67.65 with usability and learnability subscales computed at 68.4 and 64.7 respectively. Cronbach's alpha values above 0.70 are considered as being "Good" and below 0.70 are "Poor," and negative values are flagged as a coding error (Sauro, 2011). The surveys' Cronbach Alpha of 0.889 indicates an internal reliability as being "Good." The SUS scoring, descriptive statistics, and reliability check is displayed in Table 5.

Table 5

SUS Scoring and Reliability Check

Item	Score / Value
N	17
SUS	67.6
Usability	68.4
Learnability	64.7
Mean SUS Score	67.6
Standard Deviation	16.9
Cronbach Alpha	0.889
Internal Reliability	Good
Coding Check	Values appear to be coded correctly from 1 to 5

SUS Scores: Percentile Rank Conversion and Descriptive Rating

Raw responses to the ten SUS items are scaled to fall between 0 and 100. Sauro (2011) suggests it is best to convert the scaled score to a percentile score that can be communicated as a percentage and to understand how the interface compares to others. The SUS scores were

converted to percentile scales and assigned descriptive ratings to compare individual SUS data (Sauro, 2011), see Table 7. The composite mean SUS score for this study is 67 and has a percentile rank of 48%. This indicates that participants overall perceive Complete Anatomy to be usable and within a range of 48% of the products tested in the (Sauro, 2011a) database. Percentile ranks along with the descriptive ratings provides a way to compare with other SUS scores and benchmarks with interfaces across industries. This study did not compare user perceptions of other products to Complete Anatomy, but it is important to explain the context of percentile ranks of the SUS. Table 6 displays Sauro and Lewis (2012) grading scale with percentile range and grade rating. A good SUS score would be anything about a 76, which would mean it has a higher score than 75% of all products tested (Sauro, 2011). Another way to describe SUS ranking is in terms of perceived acceptability levels: Acceptable, Not Acceptable, and Marginal (Bangor 2008). Bangor (2008) states that products are passable with SUS scores above 70 and anything less is considered marginal should be subject to scrutiny for improvement.

Table 6

Curved Grading Scale for the SUS

SUS	Percentile Range	Grade
84.1 – 100	96 - 100	A+
80.8 – 84.0	90 - 95	A
79.9 – 80.7	85 - 89	A-
77.2 – 78.8	80 – 84	B+
74.1 – 77.1	70 – 79	B
72.6 – 74.0	65 - 69	B-
71.1 – 72.5	60 - 64	C+
65.0 – 71.0	41 – 59	C
62.7 – 64.9	35 – 40	C-
51.7 – 62.6	15 - 34	D
0 – 51.6	0 - 14	F

The composite mean SUS score derived for this study falls within the average level of perceived usability with a descriptive rating of “Ok,” grade of “C” and “marginal” acceptability. There were seven participants with “Acceptable” level SUS scores who rated the interface between “Good,” “Best,” and “Excellent.” Nine participants indicated “Marginal” acceptability level and rated the interface as “Ok.” There was one participant who gave the lowest scoring SUS score, deeming the product as “Not Acceptable” with a rating of “Poor.” Table 6 provides the breakdown of participant SUS scores, percentile rank, and adjective description, grade (per Sauro & Lewis), and acceptability level.

Table 7

Raw SUS Score Conversion to Percentile Ranking with Descriptive Ratings

Participant ID	SUS Score	Percentile Rank	Descriptive Ratings
P144	50	13	Adjective: Ok Grade: F Acceptability: Marginal
P294	55	20	Adjective: Ok Grade: D Acceptability: Marginal
P204	77.5	81	Adjective: Good Grade: B+ Acceptability: Acceptable
P189	82.5	94	Adjective: Excellent Grade: A Acceptability: Acceptable
P443	60	29	Adjective: Ok Grade: D Acceptability: Marginal
P403	52.5	16	Adjective: Ok Grade: D Acceptability: Marginal
P231	77.5	81	Adjective: Good Grade: B+ Acceptability: Acceptable

Table 7 Continued

Participant ID	SUS Score	Percentile Rank	Descriptive Ratings
P437	95	100	Adjective: Best Grade: A+ Acceptability: Acceptable
P286	32.5	3	Adjective: Poor Grade: F Acceptability: Not Acceptable
P348	67.5	48	Adjective: Ok Grade: C Acceptability: Marginal
P355	67.5	48	Adjective: Ok Grade: C Acceptability: Marginal
P401	82.5	94	Adjective: Excellent Grade: A Acceptability: Acceptable
P267	97.5	100	Adjective: Best Grade: A+ Acceptability: Acceptable
P274	57.5	24	Adjective: Ok Grade: F Acceptability: Marginal
P458	75	73	Adjective: Good Grade: B Acceptability: Acceptable
P399	65	41	Adjective: Ok Grade: C Acceptability: Marginal
P480	55	20	Adjective: Ok Grade: D Acceptability: Marginal

Short Flow State Scale-2 Data

The Short Flow State Scale-2 survey data were collected using Qualtrics survey. In the S FSS-2, the nine dimensions of flow state are represented as a single composite score. The short scales provide a succinct measure of the higher-order dimensional flow model consisting of the 36 items in Long Flow Scale. The S FSS-2 is suitable for a brief assessment of flow and useful when an aggregate measure of the nine flow dimensions is desired (Jackson, Eklund & Martin, 2010).

The lowest possible score on the flow scales is '1', with the highest being '5'. A low score suggests that the person's experience was not substantively "flow-like" and conversely, a high score indicates the person was undergoing a substantively "flow-like" experience." "The mid-range score of '3' on the state scales represents a "neither agree nor disagree" option.

The majority of the participants' S FSS-2 scores were in the mid-range of '3' with four participant scores at '4' and higher. A breakdown of the participant SUS and S FSS-2 scores are displayed in Table 8. The moderate scores may indicate some degree of endorsement of the item. It could also indicate some ambiguity regarding relevance of the item to the participant's experience during the dissection activity. According to Jackson, Eklund and Martin (2010), it is reasonable to interpret moderate-level scores as being neither strongly indicative that the participant has experienced the flow characteristic, nor strongly indicative that the experience did not include the flow characteristic being assessed. Those that scored '4' and higher indicates an experience that is substantively flow-like in nature. There were 12 participants who scored in the moderate '3' range, four participants with '4' or greater, and one participant under the score of '3', see Table 9 for score grouping.

Table 8

Participants SUS and S FSS-2 Scores

Participant ID	SUS Score	S FSS-2 Score
P144	50	3.44
P294	55	3
P204	77.5	4.22
P189	82.5	3.78
P443	60	3.11
P403	52.5	3
P231	77.5	4.22
P437	95	4
P286	32.5	3.44
P348	67.5	3.78
P355	67.5	2.89
P401	82.5	3.67
P267	97.5	4.44
P274	57.5	3.89
P458	75	3.22
P399	65	3.33
P480	55	3.44

Table 9

S FSS-2 Scores Grouping

Moderate (3)	Low (< 3)	High (> 3)
12 participants	1 participant	4 participants

Cognitive Walkthrough and Think-Aloud Protocol Analysis

The researcher observed participants perform a virtual dissection learning activity over Zoom. The activity was facilitated using CW with TAP. Participants verbalized their thoughts

and feelings while performing the task sequence to accomplish the CW goal. The researcher took notes during the virtual dissection activity and used the CW evaluator's guide to document participant response for each task sequence (see Table 10). The CW was conducted remotely and facilitated and recorded over Zoom.

The CW consisted of 15 tasks that needed to be executed to complete the goal. The CW task goal was for the participant to identify and label the three-dimensional relationship between small intestine and pancreas, liver, and gallbladder. The participants performed the predefined task sequence is as follows:

- Open the Complete Anatomy application
- Go to the Content Library
- Select the Search icon
- Place cursor on the search field and type "abdominal dissection"
- Select "abdominal dissection" from the list of anatomical modes
- Size and rotate the model as desired
- Select the Tools menu
- Select the Cut tool
- Select single layer for depth of cut
- Choose the "Cut line" from the Cut options
- Perform the dissection to examine the anatomical parts
- Select Done
- Size and rotate the model as desired
- Select the Pen tool and label the anatomical parts
- Select Done

Table 10

Cognitive Walkthrough Results and Observations

Participant ID	Experienced Issues	Task Issue	Observation Summary
P144	No	None	-Device used: iPad -Showed ease of use with cutting tool to perform dissection. Able to use the cut tool as desired and rotate and navigate the image to show the 3D relationship among the organs. -Preference for the 3D pen over the 2D pen.
P294	No	None	- Device used: iPad - There was initial lag with displaying the image and with 3D pen. - Showed ease of use with cutting tool to perform dissection. Able to use the cut tool as desired and rotate and navigate the image to show the 3D relationship among the organs. -Opted for the hide function (instead of cut tool) to remove parts of the rib cage and muscles to expose the liver. Participant illustrates her ease with interacting with the model, transitioning between modes and rotating the body. Once participant got a "clear enough view of the liver," rotated the model. Expressed that in this view, she can "imagine where it would be at in the body"

Table 10 Continued

Participant ID	Experienced Issues	Task Issue	Observation Summary
P294			and " like that I can twist" (as in the model for viewing angles). -Rotated the model and expressed, "I like how you can turn to have a better view from the side." "I can see the head and the tail foley and how it sits in relation to the other organs." -Participant cut the pancreas in half for "fun" and expressed, "I like how it shows the ducts." Participant goes on to express, "The details on this app is very nice." -Seemed to have fun with the experience and appreciated the details of the images. - Participant expressed that when the cut line tool does not catch the targeted organ it ends up highlighting the adjacent organ instead, "seems very touchy". -Participant cut through the liver (using multi-layer for depth of cut) and rotated the model to view the liver lobules and gall bladder.
P403	Yes	**Task #6:** Unable to exit out of "View Screen Mode" to access the Tools Menu.	- Device used: iPad -Participant was trying to find the tools menu but did not see currently in "**View Screen Mode**" and had to click on "X" on the upper right corner. Researcher assisted with this step. -Performed initial dissection electing to go from Cut Line option to Cut Between to Cut Hole options. Then back to Cut Line option. Recognized the benefit of using the Cut hole option for ease of cutting based on target area to dissect. But struggled with continuing to use the Cut hole option with denser parts like the rib cage area and did not work as effectively to cut larger portions. Was trying to cut through the layers to get to the pancreas. Proceeded to cut layer by layer until exposing the gall bladder.

Table 10 Continued

Participant ID	Experienced Issues	Task Issue	Observation Summary
P231	Yes	**Task #4:** Did not see Screens section where image is located. **Task #6:** Did not initially see that that you need to click on “X” to exit out of “View Screen Mode” to access the Tools Menu.	- Device used: Laptop with stylus -Researcher helped participant with the location of **Screens** section due to not being able to locate it. -Participant appeared comfortable making the cut dissections, exposing large parts of the intestines. -Latency with 3D pen; used 2D pen to annotate instead. -Undo function not intuitive, “I wish there was an eraser, so I don’t have to undo everything.”
P437	No	.	- Device used: iPad -Participant was able to access the Tools menu with relative ease but stated that it was not too intuitive. Accessing the Tools menu requires the user to exit out of Screen mode first. -Participant demonstrated ease with performing horizontal cuts across the layer of muscles to expose the digestive system. - Showed ease with pen tool. On using the Pen tool to annotate, participant stated, “that’s pretty easy.” While participant did not expose the pancreas hidden behind the stomach, the researcher did not consider this as usability issue and deemed oversight of instruction details of the task provided.

Table 10 Continued

Participant ID	Experienced Issues	Task Issue	Observation Summary
P286	No	None	- Device used: iPad -After selecting the image, app froze showing only the skeletal structure. Can't click or X out of screen. Took a few seconds to finally respond and showed the full image. Participant remarked, "Super laggy each time I click." Always uses Complete Anatomy from home—never on campus. -Showed ease with sizing and rotating image, using the cut tool to dissect, and using the Undo function. -Selected the 2D pen, but also used the (auto) Label tool to show there's two options. "The label gets very specific." To label as desired, one can use the pen versus the auto labeling with the Label tool. Was comfortable using both the Pen tool and the Label tool.
P348	Yes	**Task #5:** Was stuck in "View Screen Mode". **Task #12.** Used the Label tool instead of the Pen tool to annotate.	- Device used: iPad -Was stuck in "View Screen Mode". Researcher showed participant to click X to exit to proceed to size and rotate. -Used the Label tool instead of the Pen tool. -Inadvertently clicked on other areas and prompted other submenus not desired. -Was able to label all the parts and see the 3D structure.
P458	Yes	**Task #4:** Unable to find Screens section. Researcher assisted with this step. **Task #5: S**tuck in **View Screen Mode** and unable to rotate. Researcher assisted with this step.	- Device used: iPad Helped participant find the **Screens** section. Was stuck in **View Screen Mode** and unable to rotate. Explained have to X out of the **View Screen Mode** to access the model navigation functions. Showed ease with the cut tool to dissect.

Table 10 Continued

Participant ID	Experienced Issues	Task Issue	Observation Summary
P204	Yes	**Task # 12.** Ended up clearing all the markups, meant to only clear the most recent.	- Device used: Laptop with stylus -Showed ease with the cut tool to dissect. - Elected to use the 3D pen using the stylus. Changed Pen colors along the way for better visibility against the anatomy parts. 3D pen stopped working and switched to 2D pen and recognized the 2D pen works better. Ended up clearing all the markups, meant to only clear the most recent. Did not see or did not know how to bring up the Undo submenu list of all the actions taken.
P189	No	None	- Device used: iPad -Lag with image fully displaying in beginning. -Showed ease with navigating the image. - Struggled a bit with the cut tool and precision on desired cut location. Elected to try the other cut options: cut between and cut hole. Decided on cut line option and then selected multiple layer for depth of cut (instead of the single layer). Went with the "cross section" approach and rotate model to see the stomach at an angle in relationship to other organs. -Used 2D pen, then realized with moving the model it was not moving with it. Ended up using 3D to finish annotating the rest of the parts. 3D was giving a lag so went back to 2D pen.

Participants encountered usability issues while performing the dissection task in the CW session. The CW revealed challenges with locating the Screens tab (a list of modified anatomy images saved) based on the experience of participants #P231 and #P458. Exiting out of View

Screen Mode (Participants #P 403, #P348, #P458) was also not intuitive and needed researcher assistance. The interface design placement of the "X" button at the upper right corner of the application is not as intuitively visible to the user. The researcher observed participants click around the interface in attempt to figure out how to exit the current mode. When in View Screen Mode, participants were not able to intuitively "click out" of the mode which gave the perception of being "stuck."

The undo function's submenu with a list of actions taken is also not as intuitive and cumbersome when trying to undo an undesired action taken based on participants #P204 and #P231 experience. Participant #P204 ended up clearing all the annotations made and needed to dissect and annotate the part all over again. When participant #P231 attempted to undo an annotation made, the participant tried looking for an erase function. The participant was able to find the Undo button and commented, "I wish there was an eraser, so I don't have to undo everything."

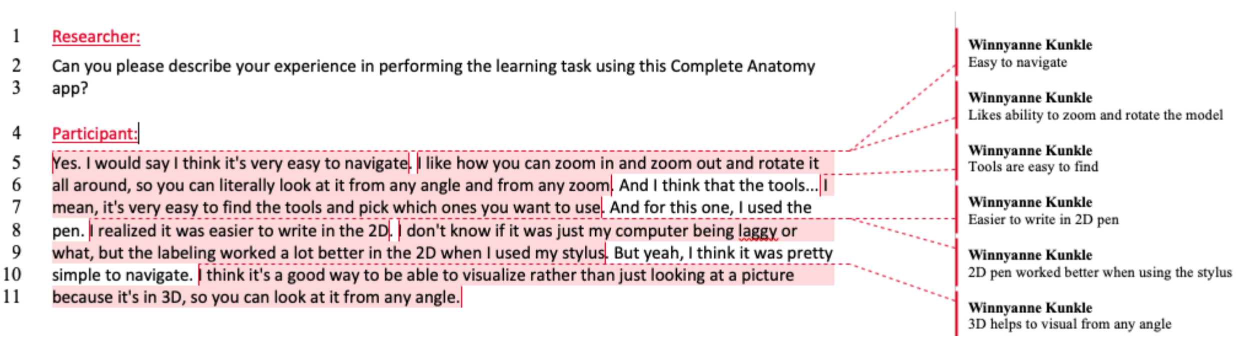
The cut tool for the virtual dissection was cumbersome related to its precision. Participant #P294 expressed that when the cut line tool does not catch the targeted organ it ends up highlighting the adjacent organ instead, "seems very touchy". The cut tool cut more than it showed at times and ended up cutting away parts and sections not intended. Participant #P437 experienced same usability issue with inconsistent precision with the cut tool in that it did not cut as expected where finger was placed on image location. The usability issues and observations are described in Table 9**.**

Semi-Structured Interviews

The researcher conducted interviews immediately following the CW activity for 10 participants. The researcher took notes during the semi-structured interview segment. The

interview session was conducted remotely. It was facilitated and recorded over Zoom. The interview audio files from Zoom were sent to Rev, a secure online transcription service, to transcribe the audio files to text. The transcriptions were created in Word format and updated to include participant ID, date of interview, type of device used (iPad or laptop), and designation of speakers (Speaker 1 as the Researcher and Speaker 2 as the Participant).

Saldana's (2011) first and second cycle coding approach was applied as a framework for coding and analyzing the qualitative data which resulted in the emergent themes. The first cycle coding methods involved initial coding to breakdown qualitative data into discrete parts, in-vivo coding to capture the participants' spoken words, and descriptive coding to summarize in a word or phrase the basic topic of a passage. The first step involved reading each transcript for familiarity of the data. The researcher then proceeded with iterative process of line- by-line review and applying the different methods to comment, memo, and code the passages of data (see Figure 8). The researcher's initial impressions were manually noted and marked in the Word document which was then shared with the advisor as a second reviewer for quality control purposes. The advisor's comments and feedback were incorporated into further coding adjustments and changes in the transcripts.


Researcher:

Can you please describe your experience in performing the learning task using this Complete Anatomy app?

Participant:

Yes. I would say I think it's very easy to navigate. I like how you can zoom in and zoom out and rotate it all around, so you can literally look at it from any angle and from any zoom. And I think that the tools... I mean, it's very easy to find the tools and pick which ones you want to use. And for this one, I used the pen. I realized it was easier to write in the 2D. I don't know if it was just my computer being laggy or what, but the labeling worked a lot better in the 2D when I used my stylus. But yeah, I think it was pretty simple to navigate. I think it's a good way to be able to visualize rather than just looking at a picture because it's in 3D, so you can look at it from any angle.

Winnyanne Kunkle
Easy to navigate

Winnyanne Kunkle
Likes ability to zoom and rotate the model

Winnyanne Kunkle
Tools are easy to find

Winnyanne Kunkle
Easier to write in 2D pen

Winnyanne Kunkle
2D pen worked better when using the stylus

Winnyanne Kunkle
3D helps to visual from any angle

Figure 8. Example of coded document in First Cycle coding phase

The researcher imported the transcripts into NVivo to perform the rest of the coding and analysis process. Line-by-line of data and then entire response to question sets were re-reviewed

and marked up with codes and comments in NVivo. NVivo assisted with convenient organization of codes, annotations, and memoing and provided quick and accurate access to data records. Throughout the iterative process of reviewing and coding the data, the researcher frequently reflected on the research questions to guide the analysis. The first cycle coding efforts produced a lengthy list of 421 raw codes as a result of the iterative process of line by line and by paragraph application of codes and comments with varying degrees of “brain dump” and discernment. The codes were organized by participants within in NVivo then copied into a master folder for aggregate cleanup of duplications, removal of items not germane to the research questions, and to prepare for categorization and pattern development. This stage of the first cycle coding marked the transition into second cycle coding.

The second cycle coding are advanced ways of reorganizing and reanalyzing data, linking unrelated items logically and connecting categories together to develop a coherent synthesis of the data (Morse, 1994). The researcher’s goal during the second cycle coding was to develop a sense of categorical and thematic organization from the array of first cycle codes. The first cycle codes were reorganized and reconfigured to eventually develop a smaller and more select list of broader categories and themes. The codifying process encompassed re-evaluation and changes to the existing codes and labels in alignment with the research questions and in context of HCI and usability concepts. The codes were then grouped for similar characteristics until all codes were categorized formulating the patterns in the data. While first cycle coding is a way to initially summarize segments of data, pattern coding, as a second cycle method, is a way of grouping those summaries into a smaller number of categories, themes, or concepts (Saldana, 2011).

The researcher provided her dissertation advisor a list of codes developed with initial categories and preliminary emerging themes. The advisor's feedback helped better align the categories to the HCI concepts and usability attributes. The process of identifying initial themes to their final development (super-ordinate themes) is illustrated in Table 11. Super-ordinate themes are developed from the process of identifying connections across emergent themes (Braun & Clarke, 2021). The corresponding descriptions of the emergent themes is defined in Table 12.

Table 11

Initial Themes, Emergent Themes, and Super-ordinate Themes List

Initial Themes	Emergent Themes	Super-ordinate Themes
Ease of Use	Ease of Use	Ease of Use
Usability	Interface-Technical	Learnability
Usability Issues	Ease of Use	Interface-Technical
Learnability	Learnability	User Satisfaction
Technical Issues	Interface-Technical	Visuospatial
Preferences	User Satisfaction	Focus/In the Zone
Visuospatial	Visuospatial	CA vs Cadaver
Preferences	User Satisfaction	
Motivation	User Satisfaction	
Satisfaction	User Satisfaction	
UI Design	Interface-Technical	
Recognition	Learnability	
Differentiation	User Satisfaction	
Focus/Zone	Focus/In the Zone	
Underutilization	CA vs Cadaver	
CA vs Cadaver	CA vs Cadaver	
Training Needs	Learnability	

Table 12

Descriptions of Super-ordinate Themes

Super-ordinate Themes	Descriptions
Ease of Use	How easy Complete Anatomy is to use to accomplish the task goal. Reactions to using Complete Anatomy include perceptions of intuitiveness and user-friendliness; emotional reactions such as frustrations, struggles, and annoyances.
Learnability	How easy Complete Anatomy is to learn and figure out to accomplish a task goal from initial and repeated use.
Interface-Technical	Technical issues encountered, including connection latency, lag time with loading the app and images.
User Satisfaction	Quality of the user's experience expressed as feelings and emotional response. Encompasses sub-categories: Preferences, User Control, Motivation
Visuospatial	Capability to imagine and visualize spatial relationships among items (anatomical parts and inter-relatedness). Encompasses sub-category: 3D Visualization.
Focus/In the Zone	Describes state and level of concentration while interacting with Complete Anatomy to perform the learning tasks. Encompasses sub-category: Engagement
CA vs Cadaver	Compares the similarities and differences between Complete Anatomy and Cadaver-based learning.

Thematic Analysis of the Cognitive Walkthrough with Think-Aloud Protocol and Interview Data

The super-ordinate themes that emerged from the interview data were related to patterns of positive and negative perceptions of ease of use and learnability, satisfaction with performing the learning tasks, visuospatial, technical challenges, focus or in the zone, and perceptions of applicability of Complete Anatomy versus cadaver-based learning with learning anatomy.

Ease of Use

Out of 10 participants, eight perceived Complete Anatomy to generally not be intuitive while two (#P204 and #P437) found it to be “user-friendly” or “intuitive” or “easy”. #P437 stated:

> "Complete Anatomy is pretty intuitive. If you're good with computers, if you have been using this kind of apps for a while…things are already pre-selected, so if you want to switch whatever you select, you have to go one or two more steps, and it's right there…everything is pretty intuitive, pretty easy to use. No, difficulties there. I think every medical student will be able to figure it out without a problem.”

The functional use of the cut tool to perform virtual dissections were “cumbersome” at times due to the area selected for removal was not always precise and required selecting and resecting until the desired section was highlighted for removal.

Experience with the use of the pen tool to annotate was straightforward for nine participants, however, three participants (#’s P294, P231, P189) were experiencing lag with the pen tool. Participant #P348 selected the label tool which auto labeled the parts instead of the pen tool annotation capability. The participant found the label tool too “detailed” and did not allow for broader identification of the anatomy part selected speaks more to the application’s learnability than its ease of use.

The undo function was also not intuitive and found to be cumbersome for three participants (#’s P204, P231, P144) needing to revert back to previous action taken when the pen or the label tool was used to identify the part— #P204 and P231 expressed desire for an “eraser” capability over the undo function. #P231 remarked:

> “I wish there was an eraser, so I don’t have to undo everything.”

#P348 questioned the undo functionality when reflecting on their experience during the interview session, commenting:

> "…the cutting tool, if I tried above the line or below the line, oh, if it's not what I want, how do I undo?"

The transition between tools and modes were not intuitive and participants (#P403, #P231, #P437, #348, #458) often struggled a bit to exit out of the current mode of dissecting (using the cut tool) to navigate and rotate the part. Participants needed to click on "Done" on upper corner to exit and then make the desired selection to cut or annotate.

Learnability

Most participants indicated that after more practice, the interface became easier to use. Complete Anatomy is an optional tool to learn anatomy and for some this study was the first time they used the app and for the majority, their first time using the dissection features (cut tools). #P144 remarked on using Complete Anatomy:

> "Once you get to use it a little bit more and you start using the functions more, it does become easier to use and then it becomes a better tool."

> #P189: "I think after watching the demonstration videos for the first session, it really became pretty intuitive..a couple of weeks later, I didn't necessarily remember, but once you reminded me that you have to make two lines for the cross-section cuts. Little things like that, I think aren't intuitive, but once you play around with it a little more and get the hang of it, I think it becomes a lot easier to use."

> #P294: "I thought the first one was more challenging than the second one really due to my unfamiliarity with the product… I've used it before to study, but more so of just trying to visualize how things are versus actually dissecting and labeling and using those

features. That was new to me…figuring out the accessibility and where the tools were and how to turn them on and how to turn them off. Sometimes I wouldn't turn off the cut tool and things would start slicing and I didn't mean for that to happen. That was confusing. But after, I guess maybe five, 10 minutes, it made more sense. And then I could navigate the product a little easier. I felt like it was useful, and I wish I knew about it earlier."

While nine participants found the pen tool (as specified to use in the activity instruction) to be straightforward, the participants electing the label tool instead can be attributed to lack of familiarity with the distinction between the two tools. Participant #P348 found the label tool too "detailed" due to its auto labeling of the part and did not allow for broader identification of the anatomy part selected. This indicates more practice or training is needed with the use of the tools to understand the difference between the pen and the label tools.

Technical Issues

There were six participants who experienced lag from the initial loading of the anatomy image or pen tool which caused some level of frustration. #P294, #P286, and #348 experienced lag while Complete Anatomy loaded the abdomen image upon selecting it at the start of the CW session. Once the image was fully downloaded the participants were able to perform the task without further delay. #P231 expressed the app was slow to respond, "I don't know if it's like my Wi-Fi or the app or whatever, but I just felt like it was always so slow to react to what I was pressing." #P294 and #P189 elected to use the 3D pen then switched to 2D for faster performance when experiencing lag using the 3D version.

The slow app response and latency that participants experienced is indicative of a combination of slow internet connectivity and not enough device resource such as Random-

Access Memory (RAM) to handle the app load at times during the use. Most of the participants experiencing these issues were at home during the CW where both the laptop and iPad were used to conduct the subsequent session. Participants joined the Zoom session with the researcher then joined the Zoom session on the iPad to perform the virtual dissection on the device. It's likely that that bandwidth consumption from connecting with both devices contributed to the latency.

Satisfaction

Most of the participants were satisfied with completing the learning tasks despite experiencing some levels of frustration with using the app tool's functionalities. They were able to complete the tasks and positively remarked on the app's ability to provide 3D visualization and high degree of interactivity--"good at adapting" to desired angle and perspective when viewing the anatomical part. Six participants (#s P204, P144, P189, P437, P403, P458) stated they were either "very satisfied" or "satisfied" with using Complete Anatomy to perform the learning tasks. #P204 expressed:

> "I was very satisfied. The tasks I thought were fairly simple to do. I was just looking for things and cutting and labeling. So I was satisfied with how I was able to visualize the different parts just by navigating the screen in different ways. I didn't have to just look at it from one point of view. Complete Anatomy really helps me to visualize it in the best way for me."
>
> #P189: "Definitely very satisfied. I think it really shows that three-dimensional structure and that's something that, going back to first- and second-year anatomy, that 3D structure is not something you can really understand from an anatomy textbook. That's something that I would spend some time in the anatomy lab, really trying to learn and figure out.

And I think this gives you an opportunity to do that outside of the lab as well at home, and anywhere else while studying."

#P437: "I was satisfied. I didn't have any hiccups along the way. Everything worked how it was supposed to work, 10 out of 10, no problems there."

Two participants were somewhat ambivalent with their satisfaction to complete the tasks and one was "not satisfied". #P294 expressed:

"I guess I'm satisfied. I don't think I'm unsatisfied. There were some minor things like the precision of the cutting and having to turn things on and off, but I felt like I accomplished the task and if it was a task given to me in a class or something that I would have done it sufficiently to be satisfied.

#P286: "…neutral either way, I wasn't dissatisfied, so I'm not going to go lower than five, but it's not like I think it's the best app in the world for learning anatomy."

#P231 who indicated "not satisfied" experienced latency on their laptop at the start of the CW dissection activity and during use of the pen tool. Participant commented, "I could have done better", and "software could have been smoother itself." As mentioned under Technical Issues, the latency could be attributed to internet connectivity and device resource.

Motivation

Participants found access to Complete Anatomy and its interactive 3D visualization capabilities conducive to motivation with learning anatomy. There was expressed appreciation with the ability to see the inter-relationships among organs and interact with the images based on their desired perspective of the anatomy. #P403 commented:

> "…having that visual supplement and reference really helped me a lot, kind of like the spatial organization of the structures and really having that image stick in my head. Like if I were to take an exam and having that image in mind of me actively like doing these maneuvers, I think it would really stick in my head and help me."
>
> #P231: "I think that when we're learning in class, it's very two dimensional…it does motivate me because there's so much more to the app than we see in class. I feel like, and it just gives you perspective to be able to see what it actually looks like all together. And then I really like that you can add layers of muscle and then take them off…I think it did motivate me to learn more because in class we don't see as much as the app does.
>
> #P204: "…definitely motivated me a lot just because before I had used Complete Anatomy, I had been used to just looking at 2D pictures where I couldn't move it and rotate it around to look at it from the different angles. So now that I have used Complete Anatomy and I know of the different tools I can use, I know that I can really enhance my learning experience because I can look at it more from the view of what it would actually be like in real life…it's motivated me a lot, especially because I really love anatomy. And now I know that I have this app, this tool that I can use to really enhance my learning experience."

Access to the application was noted to remove excuses to learning anatomy, #P144: "the app definitely takes away my excuses [to learn anatomy]." #P286 appreciated the functioning heartbeat in 3D visualization during the heart dissection activity:

> "see the heart pumping in 3D and see how the valves actually sat cause I don't think I really can spatially figure that out."

A couple participants remarked that Complete Anatomy did not necessarily motivate them to learn anatomy, but access to the tool helped as a reference tool and ability to learn anatomy in light of the remote learning over Zoom during the pandemic (#P348). #P458 noted, "…I think it does make it easier and it helps you visualize what you're doing and what you're learning, because it is 3D."

Focus or In the Zone

The researcher introduced an additional interview question, "Talk about your experience as you were working the dissection activities in terms of level of focus or being in a zone," after the interview sessions were already in progress. The researcher was not getting further insight to understanding aspects of the flow experience with the existing questions used with the first four participants. After consulting with the advisor, the question was introduced with the remaining six participants.

Five participants (#s P286, P403, P348, P294, 458) felt that they were "focused," and "really in a zone." Most recognized, however, that they were focused after figuring out what to do and overcame any cumbersome steps. The state of being focused or being in the zone or concentration while performing the activity were conditional based on individual experience. The participants expressed:

> #P286: "…once I felt like I finally got how the app worked, I was able to focus more. But when I was still trying to work on making the app work and getting all the screens loaded, which took some effort for me, I was kind of half paying attention to it and half doing other things. So I guess once it works, it's easy to fall into a zone, but it takes a long time to work."

#P403: “Yeah, I was really in a zone while doing both of the [heart and abdominal dissections] sessions because it does require a lot of concentration and a certain level of focus because you would have to I think utilize different aspects of your cognition while you're doing this task. And to do so, would require like the ultimate focus because I can't just like be out of focus and divert my attention because then I would easily lose focus on like what I'm looking for. So, that's why it really helps me stay in the zone.”

#P348: “I felt pretty focused. I was just trying to not only focus on actually dissecting it, but also focusing on trying to figure out where the tools were, how to use it, what I'm doing wrong…I was also focused not only on the dissection, but also being able to maneuver the interface.”

#P294: “I felt focused. I didn't have any distractions and I think it's more intuitive and interactive than definitely reading a textbook or going through flashcards or reviewing lecture. I think it holds your attention because you're adapting and manipulating the material and it's responding to you versus if you're using like a static image, it's not as helpful.”

#P458: “I felt like I was focused. I think once you know what you're doing then you can just do it…the first time when I was doing the heart one, I was probably less in the zone because I didn't know how to use any of those tools and I was following the directions, going back and forth.”

#P437 stated the session was too short to get into the zone, but remarked, “feels like a game," "sucks you in," "gets you engaged."

Complete Anatomy versus Cadaver

Eight participants expressed preference for cadaver-based learning over a virtual anatomy application like Complete Anatomy for anatomy dissection learning. Two participants (#P231, #P458) stated preference for Complete Anatomy as a dissection method to human cadavers and one in which felt both Complete Anatomy and cadaver learning was equally useful with both offering their strengths for learning anatomy. Most of the participants remarked cadavers as "irreplaceable" offering "valuable tactile experience" with the human anatomy. Participants thought Complete Anatomy was best used as a supplementary learning tool--to aid with learning anatomy as part of preparing for cadaver lab sessions.

Participants recognized several benefits with using Complete Anatomy, particularly for its rich and detailed 3D visual image and high degree of interactive capability that is adaptable to the user's viewing preferences. The following statements were made about Complete Anatomy on its interactive and rich 3D visualization capabilities:

> #P144: "there's definitely a value to the Complete Anatomy app in terms of identifying structure that you wouldn't be able to see actually in a cadaver lab and get as close and in depth as you want it to, because you can literally travel through an intestine on the app…When I cut through the stomach, it showed the longitudinal layer, it showed the circular layer, and then it showed the internal fold of the stomach, which is something that gets emphasized all day in medical school, when you're learning the GI system. The different muscle layers hold different functions and even the folds have different things…So when you're cutting through it, it's nice that they show it to you all at once. Because I just got through the stomach once and then it showed that muscle layer, the other muscle layer, and on the inside…When we were doing MSK, we would just click

on the bones and then it would pull it up and highlight what this connects to what, and when you pick on the certain parts of the bone, it gives the name and it does the, "Oh, it's connected to this by this, this muscle is what's used for this…it does help with visualizing like, "Oh, this is oxygenated blood, this is deoxygenated blood."

#P189: "…the pancreas was near the stomach, but I don't remember exactly where it was. Then being able to open up the app and seeing, oh, right, it was right behind the stomach."

#P348: "especially for the purposes of being able to learn where things are initially, because I know when I used it in anatomy it helped it a lot, in terms of being able to see it 3D and put through things. And, Oh, what's behind this layer of tissue, or what's behind the next layer of tissue, or above this one, or next to that one? I think it helped in terms of having that spatial awareness in terms of where the organs are, where certain muscles are…it's great being able to cut through it and see."

#P403: "…it took me a while to find the pancreas but knowing that I could take away the stomach and just go really behind and see that where the anatomical structures are located in reference to other structures, was really helpful and kind of helps with my visual sense of where these structures are."

#P231: "it just gives you perspective to be able to see what it actually looks like all together. And then I really like that you can add layers of muscle and then take them off."

#P294: "Once participant got a "clear enough view of the liver," rotated the model. Expressed that in this view, she can "imagine where it would be at in the body" and " like that I can twist" (as in the model for viewing angles)."

Participants felt that Complete Anatomy was best as a supplement to cadaver dissections, to prepare for lab sessions, and reinforce learning the topics covered in the anatomy course.

> #P204, "I think Complete Anatomy is probably the best way to prepare for that [surgery]…you can't just go into a surgery and start doing things. You have to learn at first…Complete Anatomy is really good to get you oriented to, I mean all the different parts of the human body. …[Complete Anatomy] a great first step in the anatomy learning process…"

> #P294: "It would be really useful if there were guided sessions prior to going into the lab. I don't think we should ever replace actually getting to see human cadavers before we're thrown into third year and then expected to know how organs sit in relation to each other and where things are supposed to be…"

Participants expressed that Complete Anatomy is the next best option when cadaver dissection is not offered or limited. Having access to a virtual anatomy tool was especially useful when access to the anatomy lab was not accessible during the pandemic's remote learning mode.

> #P294: "… the [Complete Anatomy] dissection is useful especially if you can't necessarily dissect yourself, like at our school where we only have prosected that we can look at things and touch them, but we can't do any of the cutting. I think that that would be of benefit."

> #P189: "…can add to that experience because you're able to practice parts of the dissection at home before going into the lab or after seeing something in the lab… I think maybe in schools where they have full cadaver lab experience where each student has their own assigned cadaver, that might be a little bit overkill, but in a school like ours,

where we have two, three cadavers for the whole class, I think adding on this app to get more experience while still having that experience with the cadaver, even if it's shorter than the experience with cadaver at other schools, that would kind of be the happy medium."

#P437: "We haven't done human dissections. So Complete Anatomy is what we have, and we have models, but I don't think that Complete Anatomy would work as a replacement of a real human cadaver, the experience is different. And if I were to have both, I would use Complete Anatomy before doing the real dissection, in order to get an idea of where everything is and then I will do a real dissection."

The importance of having a platform like Complete Anatomy to support self-study was pointed out, #P231 "Complete Anatomy is probably better because you have control over everything and you can self-study."

Participants expressed appreciation and preference for cadaver-based learning. Cadaver dissections were considered to be "irreplaceable" and "invaluable" experience for medical students.

#P144: I think cadaver labs are still useful because you're doing the cadaver lab with a supervisor who is going through and identifying everything with you… more of a realistic [referring to coloration of the anatomy]...The anatomy app is colored like a textbook, but the cadaver is structured like some of you would actually see. Granted they've been through formaldehyde and all this stuff, but the colors are still…what it actually looks like. You hold it in your hand, I think that itself is giving you some learning value that you can't really get through a virtual app or textbook."

#P286: "I think that it's just really super hard to replicate how messy the human body is on technology. Yeah. I don't think it should replace seeing a cadaver. I think we need to be able to see a cadaver. But it can be an aid, like to prepare us for the session, go in and label these parts on Complete Anatomy. And then we'll come in and look at it on a real body. I think that's perfectly fine and probably a good idea."

The coloration contrast between Complete Anatomy and cadavers were mentioned:

#P286: "… seeing a cadaver is essential because this is nothing what it looks like in person. Even the colors, in the human body, all the colors are the same and the gallbladder is green here and the pancreas is yellow here. But when you look inside the body, it's like all a slosh of pink and you're like, "I don't know what I'm looking at," until your eye can see it a lot of times. And even the cadavers that we see in school, nothing prepares you for even seeing it in surgery. I don't think it can replace truly seeing cadavers prior to going into surgery.

The emotional component of working with cadavers was pointed out where technology can't [yet] achieve:

P286: "… from an emotional standpoint, seeing inside of a human being, whether cadaver or person, it's a pretty jarring experience. And I don't think it's fair to do that to someone, especially a learner, and throw them into surgery, do it as a surgery. It should be done in a very supportive and respectful environment, the way that the anatomy lab is. And then we kind of take baby steps towards it. Because it's really jarring. Not just like, "Okay, I can look at the intestine." No. It's like, this is a human being who was living and using this. And you kind of lose that if you just do it with tech."

Merging, Comparing, and Contrasting Quantitative and Qualitative Data

A moderate score of ‘3’ in the flow score represents as neither strongly nor strongly indicative a person has experienced or not experienced flow characteristic. The participants’ composite mean flow score at 3.58 indicates the average participant leans slightly towards experiencing some flow-like experience. Only one participant’s score fall under the ‘3’ mid-point score. The minimum score at 2.89 indicate experience was not flow-like and maximum of 4.44 indicate substantive flow experience. There is some ambiguity with the scores hovering around the mid-point range related to the majority of the participants’ flow experience. The flow score descriptive statistics are displayed in Table 13.

Table 13

SUS and S FSS- 2 Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
SUS	17	67.64	16.94	32.5	97.5
S FSS-2	17	3.58	0.47	2.89	4.44

The results in the SUS mean score reflect similar ambiguity with the mean at 67.6 indicating the average participant perceived to experience average ease of use with Complete Anatomy. Another way to describe the SUS results according to the associated descriptive ratings is a “marginal” acceptable usability. Eight participant’s scores fell well below the 68-average mark (from scores of 32.5–65), two hover at 68 with 67.5 scores, and six participants perceiving higher ease of use (from 75–97.5). Figure 9 illustrates the association between the ease of use and flow scores.

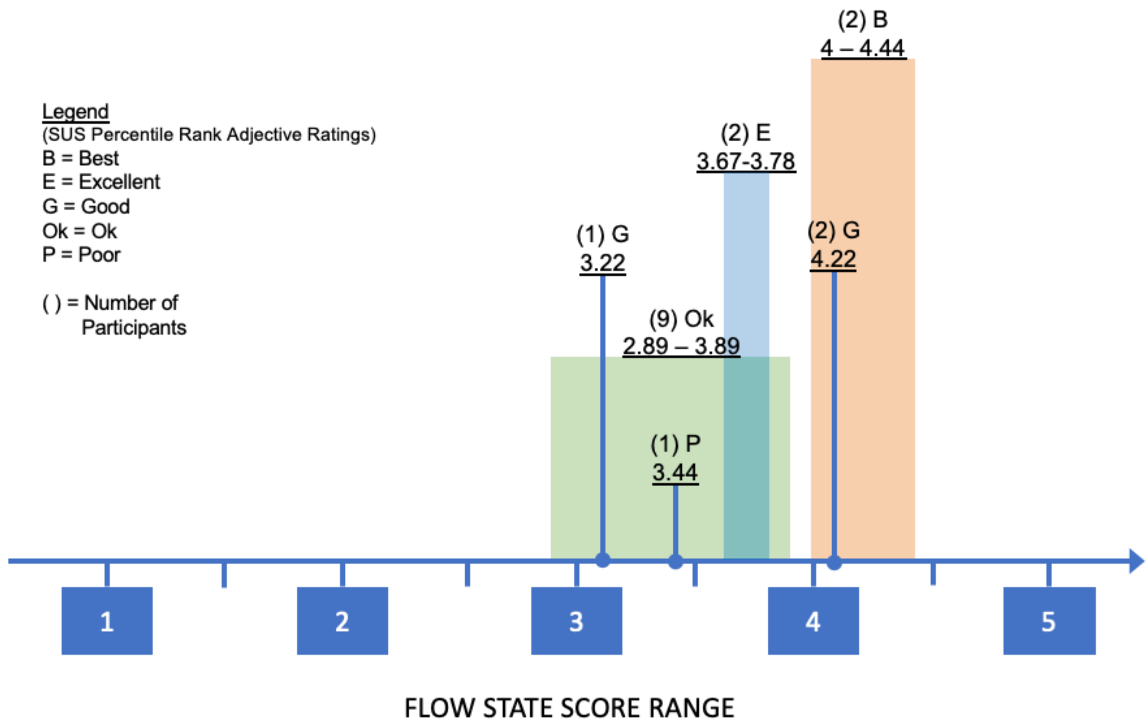


Figure 9. Flow State Score Range with SUS Descriptive Ratings

Qualitative data were collected from ten participants' CW with TAP and interview sessions. Four participants successfully performed the CW activity. The following usability issues were encountered among six participants:

- "Screens" in the navigation was not intuitive
- Exiting out of current mode was not intuitive, either as an "X" or "Done" button
- Cut tool precision
- Label versus Pen tool functionalities
- Undo function was not intuitive

The researcher also made observation notes of participants' reactions, challenges encountered, and preferences captured in Table 8.

The interview segment revealed consistent articulation of their perceptions and reactions to the overall experience over the two sessions: virtual dissections of the heart and the abdominal area. Emergent themes were drawn from both the CW with TAP and interview sessions: Ease of Use, Learnability, Interface-Technical, User Satisfaction, Visuospatial, Focus/In the Zone, CA vs Cadaver.

An approach for representation in a convergent design mixed method consists of analyzing the quantitative and qualitative data to create a table that jointly displays the results side by side (Creswell, Plano, & Clark, 2017). The researcher depicted a joint display with both congruent and discrepant results based on Lee and Green (2007). Table 14 outlines how the qualitative data expand on the quantitative data to confirm and provide contrasting narrative on the usability and flow surveys.

Table 14

Triangulating Quantitative and Qualitative Data

Quantitative Data	Qualitative Data	
	Congruent	Discordance
Eight participants had SUS scores below 68 (32.5-65) and had flow scores at mid-point range 3-3.89. The eight participants whose usability scores translate to between “Poor” and “Ok” descriptive ratings had S FSS-2 scores in the 3-3.89 range indicating possible presence of flow characteristic during the heart dissection activity.	-easier to use with each practice; "becomes a better tool" - “satisfied after figuring out the tool” - View exit mode not intuitive -Describes visualization of the anatomy in 3D "Oh, it's connected to this by this, this muscle is what's used for this." - “5-6 out of 10 for ease of use” - Second dissection easier than the first dissection session - “not so cumbersome” - Not familiar with the tools as well - “satisfied” -experienced lag with the app -struggled with cut and pen tools	- “felt focused”, No distractions - “holds your attention” - “really in a zone”; “requires a lot of concentration

Table 14 Continued

Four participants with flow scores 4 (with 5 as the highest) and above had SUS scores between 77.5-97.5. This indicates the four participants experienced substantive flow during the dissection activity and perceived usability between "Good" and "Best."	- "easy to navigate"; didn't require too much effort - "fun learning experience" - "prefers Complete Anatomy over cadaver learning" - "9/10 intuitive" - "preselected settings easy" - "sucks you in"; "feels like a game"; gets you engaged - worked as it should - "satisfied"	- "lag with pen" -struggled with using mouse to annotate -cutting tool not precise -dissection tool not intuitive - "difficult to navigate" -lag with images and pen tool -not intuitive
Three participants above 68 SUS scores (75-82.5) in the "Good" to "Excellent" rating had scores in the 3 S FSS-2 range (3.22-3.78). The three participants perceived usability indicates possible presence of flow characteristic during the heart dissection activity.	- "intuitive after the tutorials" -lag with pen - "very satisfied" with activity - "prefer Complete Anatomy over cadaver" - "intuitive after more practice" - "felt focused" after more practice - "less in the zone" in the heart dissection - "pretty satisfied"	- struggled with dissection - "stuck in the View screen" mode

Summary of Results

Chapter 4 provided a detailed overview and discussion of the quantitative and qualitative data analysis following the convergent mixed method approach. Quantitative data analysis provided descriptive statistics and interpretation of the ease of use and flow experience based on the SUS and S FSS-2 scales. The qualitative data analysis provided interpretation of the user experience to gain deeper insight into the quantitative data with five super-ordinate themes resulting from the analysis: Ease of Use, Learnability, Interface-Technical, User Satisfaction, Visuospatial, Focus/In the Zone, CA vs Cadaver.

Chapter 5

Conclusions, Implications, Recommendations, and Summary

Introduction

This chapter addresses the research questions as determined by the study findings. Conclusions discussed the extent that the study achieved its goals and addressed the strengths, weaknesses, and limitations. Additional information is provided to discuss the implications and contributions of the study. Recommendations for future research is also discussed and provided. This chapter concludes with a summary of the study.

Conclusions

The aim of the study was to examine use of the 3D virtual application in performing dissection learning tasks, to understand aspects of the user experience as assessed by ease of use and flow state. The researcher's desired outcome of the study was to gain deeper insight of the experience among students in the use of a 3D virtual anatomy application and how the design of the tool contributes to motivation to use or impede its use with learning anatomy. It is hoped that through better understanding of the students' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011), that the discussion advances on what elements of the design contribute to student satisfaction and intrinsic motivation in using 3D virtual anatomy systems compared with cadaver-based dissections.

The following research questions were successfully investigated in this study:

1. How do students rate their level of engagement as measured by flow based on their S FSS-2 scores?

Based on the participants' composite mean flow score at 3.58, the average participant had some flow-like experience during the independent session of the virtual dissection of the heart.

Of the 17, one participant's (#355) flow score fall under the '3' mid-point score at 2.89. The min score at 2.89 indicate experience was not flow-like and max score of 4.44 indicate substantive flow was experienced.

There is some ambiguity with the scores hovering around the mid-point range related to the majority of the participants' flow experience. The level of proficiency and familiarity with using a product is conducive to the development of the flow experience (Goh & Yang, 2021). The ambiguity may be attributed to the level of familiarity with using the app given the first time or seldom-use frequency among the participants. This was also the first time that the virtual dissection tool was used and explored. The observations during the CW demonstrated the effort participants applied in trying figure out how the tools worked.

Participants who experienced substantive flow during the heart dissection (in the independent session) as indicated in the flow scores of '4' and above (#s P204, P231, P437) also demonstrated ease of performing the virtual dissection and exhibited exploration behavior as observed during the abdomen dissection in the CW subsequent session. This is not to say that these participants did not encounter cumbersome moments. For instance, while #231 SUS score was "Good" and flow score at 4.22, the participant reported having some latency issues and articulated having difficulty with the cut tool's precision, "not very precise." #P204 also experienced lag which caused the 3D pen to not work as well and had to switch to the 2D pen. #437 also commented on the cut tool as not being intuitive, "…it doesn't cut where you put your fingers." This may refer to learning the functionality more than it is about precision. Participant #P267 had the highest flow score at 4.44, however, did not participate in the subsequent session therefore the researcher does not have additional insight on the experience.

2. How do students' perceptions of ease of use affect the flow experience based on the SUS and FSS-2 scores?

The result in the SUS score reflects some similarity with the flow score (3.58), with the composite mean at 67.6 indicating the average participant perceived to experience average ease of use with Complete Anatomy. Another way to describe the SUS result is that the average participant perceived Complete Anatomy as having "Marginal" acceptable usability or "Ok." Hung, Chou and Ding (2012) determined that a high usability and flow explained the user satisfaction of mobile gaming.

The participants considered Complete Anatomy's usability to be at minimum "Marginal" or "Ok" (nine participants) and at best, variations of "Good," "Excellent," and "Best" (seven participants). One participant considered the product "Not Acceptable" or "Poor" usability. The similarity of average or "mid-range" flow experience between the SUS and S FSS-2 scores among the participants is further explained with the data obtained from the CW observations and the interview session. Five participants expressed they were either "focused," or "in the zone," during their dissection activities which helps further understand the "mid-range" flow scores post independent session survey. As previously mentioned, a score of '3' may be ambiguous and indicative of a neutral flow state.

During the CW, the researcher observed states of focus or concentration as the participants interacted with the interface to complete the learning task goal. Concentration is also referred as a deeply focused attention and being engrossed in the activity (Ghani et al., 1991). Flow experience is developed when a learner begins to concentrate on the task at hand (Goh & Yang, 2021). Four participants who had a minimum flow score of '4' and experienced

substantive flow, found Complete Anatomy to be "Good," or "Best" in their perception of its usability indicating a high degree of ease of use.

3. What consequences of flow do students experience?

Participants who were in a flow state exhibited exploratory use behavior and articulated some expression of enjoyment for the experience. Liao (2006) indicated that perceived flow experience had a positive significant relationship with exploratory use. #P231 demonstrated ease with the virtual dissection activity as observed during the CW and experimented with the 3D pen and the label tool. While looking at the tools menu in the annotate tools section, participant clicked on "Sketch" function and commented "There's also a sketch tool, which is cool." #P437 also demonstrated ease using the cut tool, fluidly performing horizontal cuts across the layer of muscles to expose the digestive system. #P437 also explored the cut tool cut type options and on using the pen tool to annotate, commented, "That's pretty easy."

#P204 demonstrated ease with performing the dissection and elected to use the 3D pen and experimented with the available colors for better contrasting visibility. The pen color defaults to pink which is a similar shade with the anatomical images. Participants also expressed regarding their experience: "fun learning experience," "feels like a game," "sucks you in," "gets you engaged," as depicted in Table 13. Matute-Vallejo and Melero-Polo (2019) indicated that fun is conducive to being immersed in a state of flow.

4. What aspects of the 3D virtual application are distracting to performing the learning tasks?

All the participants encountered varying degree of technical issues or encountered cumbersome steps as they worked their way around the app and operated the tools to complete the dissection activity. Six of the participants encountered technical issues as described in

chapter four, Technical Issues section. The design elements that were cumbersome, at least initially until the participants were able to figure out how to use the tool as needed, are highlighted:

- The location and the requirement to click on “X” to exit out of “View Screen Mode” was not intuitive. Some of the participants were stuck in the “View Screen Mode” when they first pulled up the image for the dissection. Participants clicked around the screen outside of the image area perhaps with expectation that that would intuitively close the image and get to the screen navigation to access the Tools menu.
- Cut tool–The precision of the cut tool was not consistent. When placing the cut line on the desired area to cut, it sometimes selected more or less the target area needed. This required the participant to repeat the selection until it accurately selected the area.
- Label tool–For participants who selected the label tool over the pen tool to mark the parts, commented on how “too specific” or “too detailed” it was and preferred to have the option of “granularity” of the label. #P286 remarked, “Could I just say…small intestine, or does it have to say duodenum?” [or] “Call it stomach, or does it have to say gastric fold?”
- Undo–The undo submenu was not intuitive as you had to hold down the undo button for the submenu to appear. A couple of the participants (#P144 #P231) who needed to use the undo function clicked on undo several times instead of selecting from the list of steps taken to undo. There is also an option to “Undo all.” Both participants commented on desire for an erase function.

- The Screens tab which is a part of a tabbed menu appears when using search field and displays a list of images that have been modified and shared, such as the images used for the dissection activity. This was not always obvious for participants and required pointing out by the researcher.

It was interesting to see that despite these issues and the novelty of using the app, the participants were able to overcome the distractions of latency which typically occurred in the beginning of accessing the app and retrieving the image and navigate through the image and tools menu to complete the task. This assessment is consistent with the participants' own admission to being satisfied with using Complete Anatomy to perform the learning task.

5. How does flow help explain student satisfaction and motivation?

Flow experience has been shown to be a good predictor for satisfaction with e-learning platforms (Shin, 2006; Zhao et al. 2020). Most of the participants were satisfied with completing the learning tasks despite experiencing some levels of frustration between the technical issues encountered and having to figure out how certain features worked. Matute-Vallejo and Melero-Polo (2019) found that perceived ease of use does not predict flow states suggesting that learning how to operate and interact with the technology can induce states of deep immersion during the activity.

Most of the participants were satisfied with their ability to complete the task and overwhelmingly had positive responses to the 3D visualization capabilities and the interactive qualities of the app. Six participants (#s P204, P144, P189, P437, P403, P458) stated they were either "very satisfied" or "satisfied" with using Complete Anatomy to perform the learning tasks. The participants who were either not satisfied or ambivalent about being satisfied may be

attributed to the higher level of frustration between the technical issues and learnability of the app.

When a learner is in a flow state, the focused attention promotes a stronger motivation to appreciate the usefulness of the e-learning system (Buil et al., 2019). Participants found access to Complete Anatomy and its interactive 3D visualization capabilities conducive to motivation with learning anatomy. They expressed appreciation with the ability to see the inter-relationships among organs and interact with the images based on their desired perspective of the anatomy. Participants were motivated by the tool as it has the ability to show anatomy than what can typically be covered or shown in class in a 2-dimensional way, "…it does motivate me because there's so much more to the app than we see in class…gives you perspective to be able to see what it actually looks like all together," #P231. #P348 remarked, "I think it helped in terms of having that spatial awareness in terms of where the organs are, where certain muscles are."

6. How do students perceive use of the tool to learn anatomy over cadaver-based dissection?

Eight participants preferred cadaver-based learning over a virtual anatomy application like Complete Anatomy for anatomy dissection learning. Two participants stated preference for Complete Anatomy as a dissection method to human cadavers and one participant felt both Complete Anatomy and cadaver learning was equally useful with both offering their strengths for learning anatomy. Most of the participants remarked cadavers as "irreplaceable" offering "valuable tactile experience" with the human anatomy. Participants thought Complete Anatomy was best used as a supplementary learning tool–to aid with learning anatomy as part of preparing for cadaver lab sessions. The majority consensus among the participants was that access to a 3D

virtual anatomy resource such as Complete Anatomy added to their learning experience and helped with their motivation to learn anatomy. Participants recognized that 3D virtual anatomy can offer a unique learning experience on its own that cannot be replicated with cadaver-based dissection.

- Ability to perform non-destructive dissections. With cadaver dissections, the user can only perform the cuts once whereas, with a virtual solution, the learner can perform the dissections as many and as often times as needed.
- Ability to see dense systems in a detailed 3-dimensional way such as musculoskeletal system.
- Ability to see structures as close and in depth where the user can travel through the anatomy such as the intestines.

Participants also articulated desire to have used it earlier in their medical education. One was a 4th year student #P189 and one a 3rd year (#P294). There also expressed desire to continue using Complete Anatomy in residency (#P189). It's worth noting that motivation to learn anatomy may also be dependent on the cohort level. Anatomy is taught during the first two years of medical school where it is most relevant in a student's academic progress:

> #P294: "I don't know if it really motivated me to want to learn anatomy. I think it would be different if I was a first year or second year medical student, I need to know anatomy and I know that that's important."

The unique qualities that participants identified in using Complete Anatomy and the study findings are similar to what literature has revealed about cadaver-based dissections. The noted advantages of cadaver dissections provide students the hands-on experience and helping students build a 3D mental image of anatomical parts through the process of exploration and

curiosity brought on by active observation and participation in dissection (Flack & Nicholson, 2018; Gunderman & Wilson, 2005; Pawlina & Lachman, 2004). The ability of cadaver dissections to provide an authentic learning experience which engages all the senses enable students to understand anatomical structure spatial relationships that 2D representation typically cannot (Lu et al., 2017). The process of dissection helps reinforce and elaborate knowledge acquired in traditional lectures and tutorials (McLachlan et al. 2004).

Strengths, Weaknesses, and Limitations

The strength of this study was the approach to apply a convergent mixed method which consisted of collecting five points of data sources: SUS, S FSS-2, CW (observations) with TAP, and Semi-Structured Interviews. Combining the method within the novel context to investigate a 3D virtual anatomy application among medical students and the researcher's knowledge of technologies as an IT Director added to the robustness of the study. Representation of participants across all student cohort from year one to year four is also a strength.

A weakness of the study is the convenient sampling from a single institution which may be a problem for generalizability of the study findings. The sample size (N=17) is not considered a weakness as usability studies are shown to be valid even as low as five participants (Turner, Lewis, & Nielsen, 2006). A limitation of the study is the use of the short version of the flow state scale which did not provide researcher ability to independently analyze the nine dimensions of flow. The short flow version is suitable for a brief assessment of flow and the researcher aims to get an aggregate measure of the nine flow dimensions. Given the desire to understand the user experience encompassing flow as a measure of engagement in addition to ease of use, the researcher considered this the best approach based on the goals of the study.

Implications

The study has implications for educators (particularly anatomists), educational technologists, and HCI and UX practioners. The literature review conducted in the study revealed the lack of understanding of the user experience with 3D virtual anatomy and adoption of the platform among medical students. To the best of the researcher's knowledge, there are no known studies investigating ease of use and flow with 3D virtual anatomy among medical students. Findings provide insight from medical students' experience with the use of a 3D virtual anatomy application to perform virtual dissections.

HCI and UX practitioners interested in combining ease of use, flow, CW with TAP, and interview sessions to understand the user experience may find this study useful. This study expands on HCI research to incorporate flow state in addition to usability to understand students' experience with a novel 3D virtual anatomy platform. The results of ease of use and its impact to flow was discussed along with the students' satisfaction and motivation with use of the application. The study furthered the understanding of 1) ease of use and flow states 2) user experience with 3D virtual anatomy for learning 3) UX evaluation of a 3D virtual anatomy application 4) comparison of a 3D virtual anatomy application with cadaver-based dissection 5) application of convergent mixed method for UX evaluation in a 3D virtual domain.

This research also has implications for educators, particularly anatomists, interested in leveraging 3D anatomy as a supplementary educational technology tool for teaching. The study findings reveal the benefits of incorporating a 3D anatomy application as a supplement to their in-class teaching and learning. Educational technologists who support technologies and tools in an academic setting can benefit from these findings. Those making decisions around 3D anatomy tools in the context of cadaver-based learning may also find this useful. There is a real potential

for 3D virtual anatomy platforms to address the challenges with learning anatomy as the literature reveals (not enough time in the anatomy course, difficulty with learning 3D content such as a human body in mostly 2D learning material, challenges with availability of cadaver-based dissection, access to cadaver labs in times of pandemic).

Multiple possibilities exist for future studies. Additional research should be conducted for an extended duration to rigorously assess flow. Some students remarked that the half hour session to perform the heart dissection was “not long enough to get into the zone.” Research should also be conducted using the long version of the flow state scale which provides better understanding of each flow dimension. Use of the shorter version captured the aggregate flow score and could not evaluate at the dimension level. It would also be helpful to conduct the study as part of the entire duration of the anatomy course and assess how the flow experience impacts student learning performance.

A study conducted with students who have hands-on experience with human cadaver dissection and comparing their experience with the use of a 3D virtual anatomy for dissection would be an interesting side-by-side assessment.

Recommendation

The following recommendations are for educators, educational technologists, information technology professionals responsible for making decisions on the selection, evaluation, and implementations of 3D virtual platforms as a learning resource. This is also useful for the general consideration of implementing a technology solution or improving technology adoption.

Academic institutions should work to promote and support use of technologies such as 3D virtual platform that can enhance student learning in rich and novel way. Training should be developed and provided to students on the virtual platform that is intentional and thoughtful

about how to leverage the tool to enhance the student's learning experience, as well as reinforce learning objectives following insight from UX assessments. Training strategy should consider the features and functionality that is most useful and relevant to support the course's learning objective and pedagogy. Use of the platform should be incorporated into the curriculum in an active and integral manner to augment the learning experience as an alternative to simply providing it as an educational technology resource. As such, similar training should be provided to instructors so that they are able to utilize it in class and can understand the student's experience and leverage it for teaching. UX assessments should be conducted as part of evaluating the effectiveness of novel technologies such as 3D virtual systems to understand how the design, features, and functionality support and enrich the goals for incorporating the solution in an academic setting.

Summary

The study sought to investigate the user experiences among medical students in their use of a 3D virtual anatomy application for learning. The user experience encompassed ease of use and investigated the aggregate constructs of flow (i.e., challenge-skill balance, action-awareness merging, clear goals, unambiguous feedback, concentration on task, sense of control, loss of self-consciousness, time transformation, and autotelic experience). The literature review revealed several factors that influenced the focus, approach, and goals of the study:

- Despite the variety of e-learning, computer-aided learning resources, and virtual anatomy systems offering the tools for interactive engagement, students show an overwhelming preference for cadaveric dissection and traditional methods of learning (Davis et al., 2014; Preim & Saalfeld, 2018).

- UX factors and adoption are not well understood with regards to the use of 3D virtual anatomy software within the context of anatomy learning (Peterson & Mlynarczyk, 2016; Preim & Saalfield, 2018).
- HCI researchers recognizing the limitations of the instrumental, task-oriented aspects of usability assessments and promote focusing on non-utilitarian qualities of the user experience (i.e. emotions, enjoyment, aesthetics, engagement, etc.) that captures the users' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011).
- HCI researchers recognize the minimum level of usability needed for engagement with the system to be possible (O'Brien & Toms, 2008).
- Flow has been linked to higher user satisfaction and motivation with interactive technologies such as gaming (Hung et al., 2012), simulation (Buil et al., 2018) and online learning environments (Esteban-Millat et al. 2014).
- Finneran and Zhang (2002) suggest that ease of use should be considered in evaluating flow experience within a computer-mediated environment as it has the potential to influence elements of flow.

The study was guided by the following research questions.

1. What consequences of flow do students experience?
2. What aspects of the 3D virtual tool are distracting to performing the learning tasks?
3. How do students' perception of ease of use affect the flow experience based on the SUS and S FSS-2 scores?
4. How do students rate their level of engagement as measured by flow based on their S FSS-2 scores?

5. How does flow help explain student satisfaction and motivation?
6. How do students perceive use of the tool to learn anatomy over cadaver-based dissection?

The convergent mixed method approach was applied to collect, merge, and analyze the quantitative and qualitative data. The convergent mixed-method is useful when the researcher wants to compare quantitative statistical results with qualitative findings for a complete understanding of the research problem (Creswell & Clark, 2017). The study used survey instruments, observations of CW with TAP, and interview sessions.

Participant demographic information was collected using Qualtrics survey. The data captured included age, gender, age group, and cohort level. Participant data (N = 17) were collected using Qualtrics survey. Participants' perceived ease of use was measured using the System Usability Scale survey by John Brooke (1996), an established usability measurement tool. The SUS survey was distributed to participants using Qualtrics. Participants completed the SUS survey following completion of the virtual dissection as part of the Independent Session. The Short Flow State Scale-2 survey was collected using Qualtrics survey. In the S FSS-2, the 9 dimensions of flow state are represented as a single composite score. The short scales provide a succinct measure of the higher-order dimensional flow model consisting of the 36 items in Long Flow Scale. The S FSS-2 is suitable for a brief assessment of flow and useful when an aggregate measure of the nine flow dimensions is desired (Jackson, Eklund & Martin, 2010).

The composite mean SUS score derived for this study falls within the average level of perceived usability with a descriptive rating of "Ok," grade of "C" and "marginal" acceptability. There were 7 participants with "Acceptable" level SUS scores who rated the interface between "Good," "Best," and "Excellent." Nine participants indicated "Marginal" acceptability level and

rated the interface as “Ok.” There was one participant who gave the lowest scoring SUS score, deeming the product as “Not Acceptable” with a rating of “Poor.”

The majority of the participants’ S FSS-2 scores were in the mid-range of ‘3’ with four participant scores at ‘4’ and higher. The moderate scores may indicate some degree of endorsement of the item. It could also indicate some ambiguity regarding relevance of the item to the participant’s experience during the dissection activity. According to Jackson, Eklund and Martin (2010), it is reasonable to interpret moderate-level scores as being neither strongly indicative that the participant has experienced the flow characteristic, nor strongly indicative that the experience did not include the flow characteristic being assessed. Those that scored ‘4’ and higher indicates an experience that is substantively flow-like in nature. There were 12 participants who scored in the moderate ‘3’ range, four participants with ‘4’ or greater, and one participant under the score of ‘3’.

Qualitative data collection was facilitated using CW with TAP and semi-structured interview sessions. The researcher observed participants perform a virtual dissection learning activity over Zoom. The activity was facilitated using CW with TAP. Participants verbalized their thoughts and feelings while performing the task sequence to accomplish the CW goal. The researcher conducted the interview segment immediately following the CW activity. The researcher took notes during the semi-structured interview segment. The interview session was conducted remotely and facilitated and recorded over Zoom.

Saldana’s (2011) first and second cycle coding approach was applied as a framework for coding and analyzing the qualitative data which resulted in the emergent themes. The first cycle coding methods involved initial coding to breakdown qualitative data into discrete parts, in-vivo coding to capture the participants’ spoken words, and descriptive coding to summarize in a word

or phrase the basic topic of a passage. The qualitative data analysis provided interpretation of the user experience to gain deeper insight into the quantitative data with five super-ordinate themes resulting from the analysis: Ease of Use, Learnability, Interface-Technical, User Satisfaction, Visuospatial, Focus/In the Zone, CA vs Cadaver.

Usability factors are known to impede the successful adoption of 3D anatomy tools, but existing research is inconclusive to determine what in the design of these tools affect its successful use and satisfactory experience (Nuland et al.,2017; Peterson & Mlynarczyk, 2016; Preim & Saalfield, 2018). The researcher hoped that through better understanding of the students' internal state in their interaction with the product (Bargas-Avila & Hornbaek, 2011), that study advances the discussion on what elements of the design contribute to student satisfaction and intrinsic motivation in using 3D virtual anatomy platforms compared with cadaver-based dissections. The study findings revealed two themes related to the design:

1. Usability problems that contributed to feelings of frustration and cumbersome experience in those moments of interacting with the interface and tools during the dissection activity.
    - The location and the requirement to click on "X" or "Done" to exit or transition between modes was not intuitive.
    - The cut tool was not always precise and required repeat attempts to achieve desired cut selection.
    - The undo submenu was not intuitive as you had to hold down the undo button for the submenu to appear.
    - The Screens tab which is a part of a tabbed menu appears when using search field and displays a list of images that have been modified and shared, such as the images used

for the dissection activity. This was not always obvious for participants and required pointing out by the researcher.

2. Design elements, features, and functionalities that contributed to student satisfaction and motivation to use the application to learn anatomy. Participants recognized that 3D virtual anatomy can offer a unique learning experience on its own that cannot be replicated with cadaver-based dissection.
    - Ability to see structures and dense systems (i.e. musculoskeletal system) as up-close and in-depth as desired with rich 3-dimensional visualizations where the user can travel through the anatomy (i.e. intestines).
    - Ability to perform non-destructive dissections. With cadaver dissections, the user can only perform the cuts once whereas, with a virtual solution, the learner can perform the dissections as many and as often times as needed.

The unique qualities that participants identified in using Complete Anatomy and the study findings, is similar to what literature has revealed about cadaver-based dissections. The noted advantages of cadaver dissections provide students the hands-on experience and helping students build a 3D mental image of anatomical parts through the process of exploration and curiosity brought on by active observation and participation in dissection (Flack & Nicholson, 2018; Gunderman & Wilson, 2005; Pawlina & Lachman, 2004). The ability of cadaver dissections to provide an authentic learning experience which engages all the senses enable students to understand anatomical structure spatial relationships that 2D representation typically cannot (Lu et al., 2017). The process of dissection helps reinforce and elaborate knowledge acquired in traditional lectures and tutorials (McLachlan et al. 2004).

The study furthered the understanding of 1) ease of use and flow states 2) UX with 3D virtual anatomy for learning 3) UX evaluation of a 3D virtual anatomy application 4) comparison of a 3D virtual anatomy application with cadaver-based dissection 5) application of convergent mixed method for UX evaluation in a 3D virtual domain. Multiple possibilities exist for future studies. Additional research should be conducted for an extended duration to rigorously assess flow. Some students remarked that the half hour session to perform the heart dissection was "not long enough to get into the zone." Research should also be conducted using the long version of the flow state scale which provides a better understanding of each flow dimension. Use of the shorter version captured the aggregate flow score and could not evaluate at the dimension level. It would also be helpful to conduct the study as part of the entire duration of the anatomy course and assess how the flow experience impacts student learning performance. A study conducted with students who have hands-on experience with human cadaver dissection and comparing their experience with the use of a 3D virtual anatomy for dissection would be an interesting side-by-side assessment.

Appendix A

3D Virtual Anatomy Usability Surveys

System Usability Scale (Brooke, 1996)

Participant ID:____________________ Date:____________

For each of the following statements, mark **one** box that best describes your reactions to Complete Anatomy.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I think that I would like to use Complete Anatomy frequently.	☐	☐	☐	☐	☐
2. I found Complete Anatomy unnecessarily complex.	☐	☐	☐	☐	☐
3. I thought Complete Anatomy was easy to use.	☐	☐	☐	☐	☐
4. I think that I would need assistance from a technical person to be able to use Complete Anatomy .	☐	☐	☐	☐	☐
5. I found the various functions in Complete Anatomy were well integrated.	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in Complete Anatomy.	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use Complete Anatomy very quickly.	☐	☐	☐	☐	☐
8. I found Complete Anatomy very cumbersome/awkward to use.	☐	☐	☐	☐	☐

9. I felt very confident in using Complete Anatomy.	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with Complete Anatomy.	☐	☐	☐	☐	☐

Appendix B

Short Flow State Scale-2 (S FSS-2) Sample Items

(Jackson, Martin, & Eklund, 2008)

I know clearly what I want to do

My attention is focused entirely on what I am doing

I was not concerned with what others may have been thinking of me

Things just seemed to be happening automatically

I found the experience extremely rewarding

Appendix C

Learning Tasks

<u>Learning Task (Independent Session)</u>

In Complete Anatomy, perform a dissection of the heart using the cut tools. Select **multiple layers** for depth of cut and **cut line** option. Use the pen tool to label the anatomical parts for items **a** and **b.**

a) Recognize the three-dimensional relationship of the heart chambers.

b) Distinguish between aortic, pulmonary, mitral, and tricuspid valves.

<u>Learning Task (Subsequent Session)</u>

In Complete Anatomy, perform a dissection of the abdominal region using the cut tools. Select **multiple layers** for depth of cut and **cut line** option. Use the pen tool to label the anatomical parts.

a) Identify the three-dimensional relationship between the stomach, small intestine, pancreas, liver, and gallbladder.

Appendix D

Resource List

Hardware	Users
Laptop with webcam and mic	Researcher and Participants
iPad	Researcher and Participants
Software and Services	
NVivo 1.5	Researcher
Microsoft Office Suite	Researcher and Participants
3D4Medical Complete Anatomy	Researcher and Participants
Qualtrics	Researcher
Transcription (Rev)	Researcher
Internet Connectivity	Researcher and Participants
Instruments	
The Flow Manual	Researcher
Flow Remote Online Survey Licenses	Researcher

Appendix E

Institutional Review Board Documentation (NSU)

NOVA SOUTHEASTERN UNIVERSITY
Institutional Review Board

MEMORANDUM

To: WINNYANNE KUNKLE
College of Engineering and Computing

From: Cristina Garcia-Godoy, D.D.S., M.P.H., C.C.R.P.
Chair, Institutional Review Board

Date: October 16, 2020

Subject: IRB Exempt Initial Approval Memo

TITLE: Investigating the User Experience with a 3D Virtual Anatomy Application– NSU IRB Protocol Number 2020-490

Dear Principal Investigator,

Your submission has been reviewed and approved by the Institutional Review Board on **October 16, 2020**. You may proceed with your study.

Please Note: If you receive stamped copies of consent, assent, and recruiting materials indicating approval date, these documents must be used when recruiting and consenting or assenting participants.

Level of Review: Exempt

Type of Approval: Initial Approval

Exempt Review Category: Exempt 2: Interviews, surveys, focus groups, observations of public behavior, and other similar methodologies

Post-Approval Monitoring: The IRB Office conducts post-approval review and monitoring of all studies involving human participants under the purview of the NSU IRB. The Post-Approval Monitor may randomly select any active study for a Not-for-Cause Evaluation.

Page **1** of **2**

3301 College Avenue • Fort Lauderdale, Florida 33314-7796
(954) 262-5369 • 866-499-0790 • Fax: (954) 262-3977 • Email: *irb@nova.edu* • Web site: *www.nova.edu/irb*

Final Report: You are required to notify the IRB Office within 30 days of the conclusion of the research that the study has ended using the IRB Closing Report Form.

Translated Documents: No

Please retain this document in your IRB correspondence file.

CC: Ling Wang, Ph.D.

Laurie Dringus, Ph.D.

Appendix F

Institutional Review Board Documentation (FIU)

FIU FLORIDA INTERNATIONAL UNIVERSITY

Office of Research Integrity
Research Compliance, MARC 414

Dr. Winnyanne Kunkle
File

W

January 6, 2021
"Investigating the User Experience with a 3D Virtual Anatomy Application"

study was found to be in compliance with this institution's Federal Wide Assurance (00000060).

IRB-21-0003			01/05/21
109301		**IRB Expiration Date:**	01/05/24

As a requirement of IRB Approval you are required to:

Submit an IRB Amendment Form for all proposed

Submit the IRB Renewal Form at least 30 days in advance of the study's expiration date.
or discontinued.

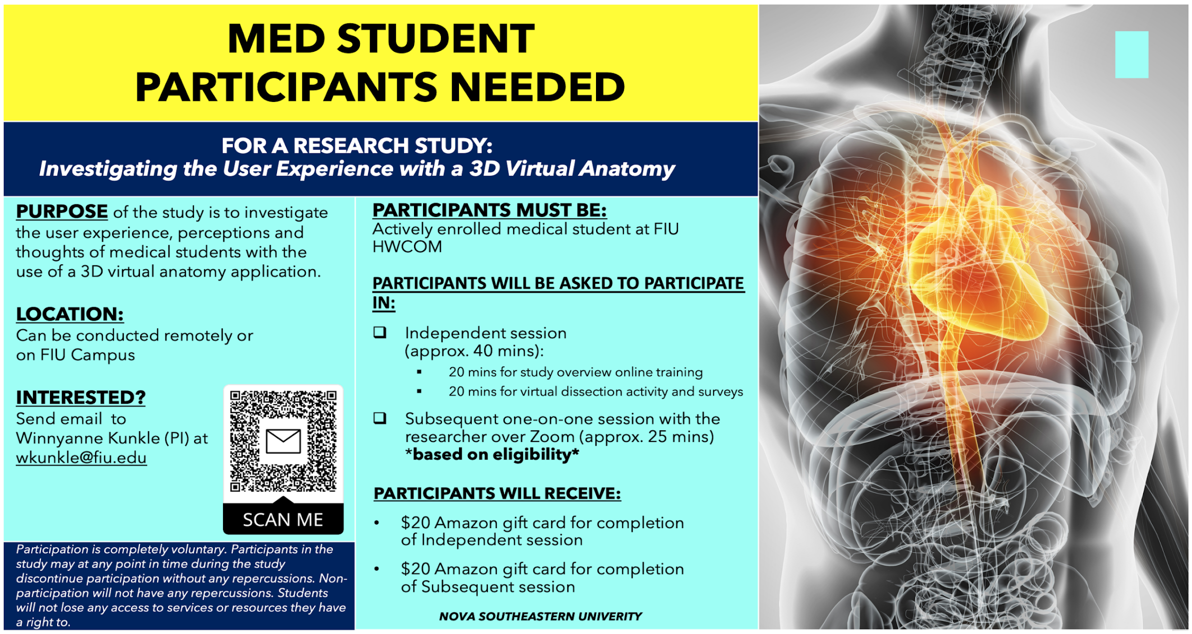
HIPAA Privacy Rule:

Special Conditions: N/A

For further information, you may visit the IRB website at http://research.fiu.edu/irb.

Appendix G

Recruitment Flyer



Appendix H

Email Template—Recruitment Response

Email Template: Invitation to Participate in the Study, Investigating the User Experience with a 3D Virtual Anatomy Application

Dear ____,

Thank you for your interest in this study. My name is Winnyanne Kunkle, and I am the Director of IT in the College of Medicine and also the research study PI. This study is part of my dissertation research with Nova Southeastern University in fulfillment of the doctoral program requirement.

Before you decide it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information carefully and let me know if there is anything that is not clear or if you would like more information.

What is this study is about?

The aim of the study is to evaluate the use of a 3D virtual anatomy application in performing dissection learning tasks, to understand
aspects of user experience as assessed by ease of use and flow. The researcher's desired outcome of the study is to gain a deeper insight of the human-computer interaction experience among students in the use of a 3D virtual anatomy application and how the design of the application contributes to motivation to use the tool or impede its use with learning anatomy. It is hoped that through a better understanding of the students' internal state in their interaction with the product, that the discussion advances on what design elements contribute to student satisfaction and intrinsic motivation in using 3D virtual anatomy systems.

Am I eligible?

All currently enrolled medical student at FIU HWCOM is eligible to participate in the study.

What is involved in participating in the study?

The entire study is conducted remotely. If you agree to be in the study, you will be asked to do the following:

1. **View an online RISE module for the Study Overview.** The module will provide information on two main parts of the study: Independent and Subsequent

Sessions and instructions on participating in the session activities and surveys. It will take approximately 5 minutes to go over the module.

2. **Complete training using online Complete Anatomy tutorial videos covering the following functionalities**: Search, Navigating the Model, Cut and Dissect, Pen Tool, Clear tools. It will take approximately 10 minutes to view the videos.

3. **Complete one or both sessions: Independent and Subsequent**

- All participants are eligible to participate in the Independent Session. The Independent Session is performed on your own time.

- The Subsequent Session will be conducted as a follow-up with a small subset of eligible participants who have completed the Independent Session and corresponding surveys. This session will be conducted one-on-one with the researcher over Zoom and has two parts: virtual dissection activity and interview segment.

What is the risk to me?

This research study involves minimal risk to you. To the best of our knowledge, the things you will be doing have no more risk of harm than you would have in everyday life.

Will I be compensated?

You will receive a one-time payment of a $20 Amazon gift card for completing the Independent Session and corresponding surveys. The payment will be provided within 5 days of completion.

Additional compensation of a one-time $20 Amazon gift card will be provided if you participate and eligible for the Subsequent Session and complete the session activities. If you only complete one of the two activities (virtual dissection OR interview segment), the payment will be prorated to a $10 Amazon gift card. The payment will be provided within 5 days of completion.

A participant may receive a total of $40 in Amazon gift card for completing both the Independent and Subsequent sessions.

Study Consent

Remember that participation is completely voluntary. Participants in the study may at any point in time during the study discontinue participation without any repercussions. Non-participation will not have any repercussions. Students will not lose any access to services or resources they have a right to.

Attached you will find the FIU study consent form for this research. You will find the information presented in this email covered in the FIU consent form. I encourage the opportunity to review and answer any questions you may have regarding the study consent in a meeting over Zoom or by phone.

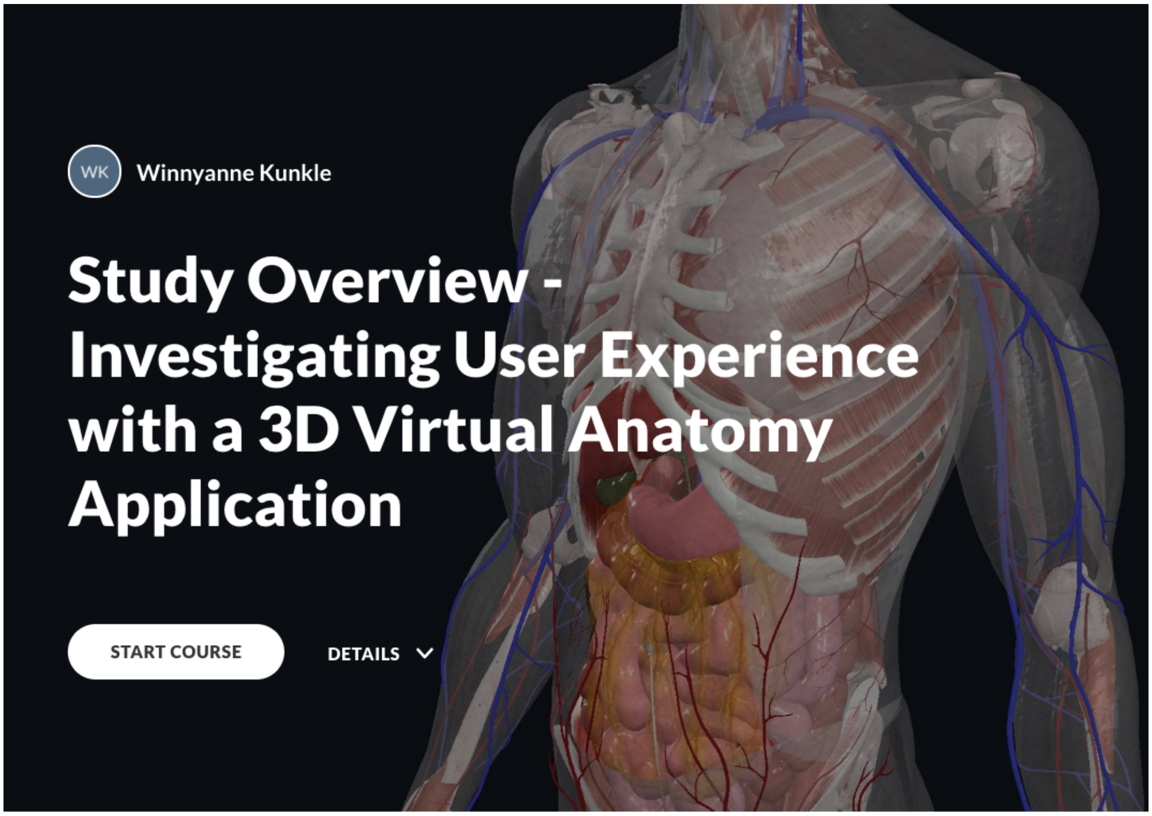
If after careful review of this email and the FIU study consent form you decide to participate, please sign the form and email back to wkunkle@fiu.edu.

If you have any questions regarding the study, this email, or the consent form, please do not hessite to reach out to me at wkunkle@fiu.edu or phone, 305-812-6832.

Thank you,
Winnyanne Kunkle

Appendix I

Articulate Rise Module—Study Overview



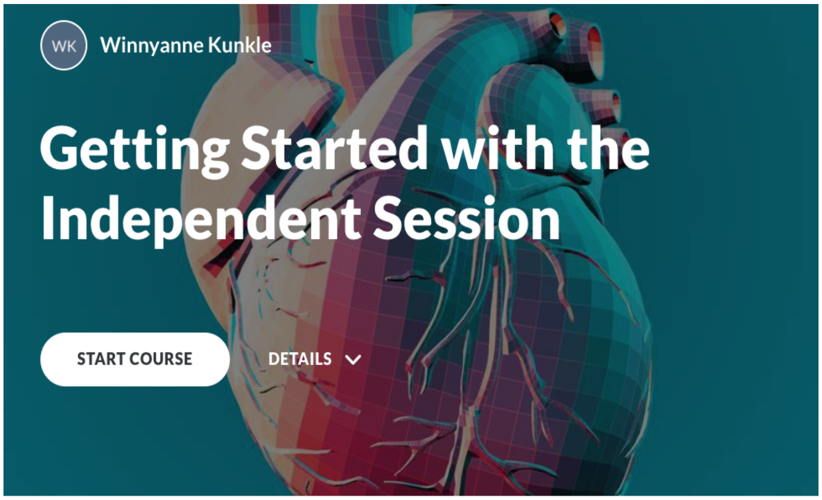
This module is for participants in the study, ***Investigating User Experience with a 3D Virtual Anatomy Application***. This module is for information only and provides the purpose and overview of the study. It will take approximately 5 minutes to go over this module.

Please be reminded that participation in this study is completely voluntary. There will be no repercussions for stopping at any time nor lose access to any services and resources you have a right to. For any questions, please contact the PI, Winnyanne Kunkle, at wkunkle@fiu.edu or 305-812-6832.

- What is this study about?
- Study Outline
- Complete Anatomy Tutorial Videos
- Study Procedures
- Gift Card Compensation
- Next Steps

Appendix J

Articulate Rise Module—Getting Started with the Independent Session



This module is for participants who have reviewed the Study Overview and are ready to proceed with the **Independent Session** in the study, ***Investigating User Experience with a 3D Virtual Anatomy Application***.

Please be reminded that participation in this study is completely voluntary. There will be no repercussions for stopping at any time nor lose access to any services and resources you have a right to. For any questions, please contact the PI, Winnyanne Kunkle, at wkunkle@fiu.edu or 305-812-6832.

- Complete Anatomy Tutorial Videos
- Getting Started with the Independent Session
- Participating in the Subsequent Session
- Thank you!

Appendix K

Email Template—Invitation to Participate in Subsequent

Email Template: Invitation to participate in Subsequent Session in the Study: Investigating the User Experience with a 3D Virtual Anatomy Application

Dear ____,

You are invited you to participate in the **Subsequent Session** of the study, *Investigating the User Experience with 3D Virtual Anatomy.* You are eligible to participate because you have fully completed the Independent Session of the study and the corresponding surveys.

What is involved in the Subsequent Session?
This session will be conducted one-on-one with the researcher over Zoom and has two parts: virtual dissection activity and interview segment.

The researcher will observe and make observation notes of participants' interaction with Complete Anatomy during the virtual dissection activity as well document the interview segment. The researcher will conduct the virtual dissection activity using usability methods, cognitive walkthrough and think-aloud protocol. The session will be recorded using the Zoom recording functionality. The recording will be used to reliability work with the participant's spoken words for the transcription process. The recording allows the researcher to refer to the source for further clarity or check on inaccuracies that may occur in the transcript. The data collection methods used in the Subsequent Session will provide the researcher further insight into the user experience with Complete Anatomy.

> **Virtual dissection activity** (Duration: approx.15 minutes) - Participants will perform a learning task as part of the session involving a virtual dissection of the abdominal area. The activity has a specific goal with a predefined set of tasks. The participant will be encouraged to verbalize their thoughts, actions, and feelings while interacting with the application to accomplish the learning task goal.
>
> **Interview segment** (Duration: approx.10 minutes) - Participants will participate in a one-on-one interview with the researcher. The researcher will ask participants types of questions related to their experience with using Complete Anatomy to perform a virtual dissection learning task such as, "How intuitive or cumbersome was Complete Anatomy," "Describe how satisfied you were with your experience in using Complete Anatomy," and "How did Complete Anatomy motivate you to want to learn anatomy."

Is there compensation for the Subsequent Session?
Compensation of a one-time $20 Amazon gift card will be provided if you participate in the Subsequent Session and complete the session activities. If you only complete one of the two activities (virtual dissection OR interview segment), the payment will be prorated to a $10 Amazon gift card. The payment will be provided within 5 days of completion.

Voluntary Participation
Remember that participation is completely voluntary. Participants in the study may at any point in time during the study discontinue participation without any repercussions. Non-participation will not have any repercussions. Students will not lose any access to services or resources they have a right to.

If you have any questions and/or agree to participate in the Subsequent Session, please reply to this email or contact me at 305-812-6832. If you proceed with the subsequent study, we can coordinate time to schedule the Zoom session at your convenience.

Appendix L

Email Template—Completion of the Independent Session

Email template: Completion of Independent Session - 3D Virtual Anatomy Study

Dear ____,

Thank you so much for your participation in the study, Investigating User Experience with 3D Virtual Anatomy.

This email is confirmation of your completion of the Independent Session. I have issued your study compensation of a $20 Amazon gift card which you will receive through your FIU email, ____.

Please let me know if you don't receive it in the next few minutes or have any issues.

Thank you!
Winnyanne Kunkle

Appendix M

Email Template—Completion of the Subsequent Session

Email Template: Completion of Subsequent Session - 3D Virtual Anatomy Study

Dear _____,

Thank you so much for your participation in the study, Investigating User Experience with 3D Virtual Anatomy.

This email is confirmation of your completion of the Subsequent Session. I have issued your study compensation of a $20 Amazon gift card which you will receive through your FIU email, _____.

Please let me know if you don't receive it or have any issues.

Thank you!

Appendix N

Email Template—Subsequent Dissection Activity Document

SUBSEQUENT SESSION:
VIRTUAL DISSECTION ACTIVITY WITH TASK SEQUENCE

STUDY:
INVESTIGATING THE USER EXPERIENCE WITH 3D VIRTUAL ANATOMY APPLICATION

<u>Goal:</u> **Identify and label the three-dimensional relationship between the stomach, small intestine, pancreas, liver, and gallbladder.**

- Open the Complete Anatomy application
- Select the **Search** icon
- Type "digestive system dissection" in the Search field
- Select "digestive system dissection" under Screens
- Size and rotate the model as desired
- Select the **Tools** menu
- Select the **Cut tool**
- Select **single layer** for depth of cut
- Choose cut "**Line**" from the Cut options
- Perform the dissection to examine the anatomical parts
- Size and rotate the model as desired
- Select the **Pen tool** and label the anatomical parts
- Select **Done**

Appendix O

Email Template—Study Informed Consent and Next Steps

Email template: Study Informed Consent Signed and Next Steps

Dear ___,

Thank you for agreeing to participate in the study, Investigating User Experience with 3D Virtual Anatomy. Please find attached the completed signed copy of the FIU study consent form.

TO GET STARTED:

- Your assigned Participant ID is: xxxx. You will use this Participant ID for completing the 4 surveys as part of the Independent Session dissection activity.
- View the Rise Module for information on the study overview and getting started with the Independent Session. Click here to access the module.

If you have any questions, please don't hesitate to contact me.

Appendix P

Demographics Questionnaire

Thank you for participating in the study, Investigating the User Experience of a 3D Virtual Anatomy System. This study is conducted as part of the Nova Southeastern University dissertation research. This survey is confidential.

Directions: Please complete the demographic survey. **Do not include your real name on this survey.**

Participant ID: _______________

Gender:

M ___

F ___

Other ______

Age:

18-24____

25-34____

35-44____

Cohort: ____

Appendix Q

Attestation of Completion of the Learning Tasks

Participant is acknowledging completion of the learning task performed in Complete Anatomy in the Independent Session. Completion of this task is a requirement for completing the SUS and S FSS-2 surveys. Please DO NOT include your real name on this form.

PARTICIPANT ID: ____________________________ **DATE:** ____________________

Learning Task (Independent Session)

In Complete Anatomy, perform a dissection of the heart using the cut tools. Select **multiple layers** for depth of cut and **cut line** option. Use the pen tool to label the anatomical parts for items **a** and **b.**

a) Recognize the three-dimensional relationship of the heart chambers.

b) Distinguish between aortic, pulmonary, mitral, and tricuspid valves.

Appendix R

Total Estimated Time Expected for Completion Per Student Activity

ACTIVITY NAME	ESTIMATED DURATION
Completion of Complete Anatomy Training Videos: Search, Cut and Dissect, Navigating the Model	10 minutes
Completion of Demographics Survey	1 minute
Perform Independent Session Learning Tasks	15 minutes
Completion of SUS Questionnaire	5 minutes
Completion of S FSS-2 Questionnaire	5 minutes
Completion of the Attestation form	1 minute
Subsequent session: Completion of the Cognitive Walkthrough with Think-Aloud Method	10 minutes
Interview session	15 minutes
TOTAL TIME	**1:02:00**

Appendix S

Cognitive Walkthrough Task and Evaluator's Documentation Guide

	Will the user try to achieve the right effect?	**Will the user notice that the correct action is available?**	**Will the user associate the correct action with the desired effect?**	**If the correct action is performed, will the user see that progress is being made towards the solution of the task?**	**Notes**
<u>Task Goal:</u> Identify and label the three-dimensional relationship between small intestine and pancreas, liver, and gallbladder.					
Open the Complete Anatomy app					
Select the Search icon					
Place cursor on the search field and type "abdominal dissection WK study"					
Select "abdominal dissection WK study" from the list of anatomical models					
Size and rotate the model as desired					
Select the Tools menu					
Select the Cut tool					
Select single layer for depth of cut					

Choose the "Cut line" from the Cut options					
Perform the dissection to examine the desired anatomical parts					
Select Done					
Size and rotate the model as desired					
Select the Pen tool and label the anatomical parts					
Select Done					

Appendix T

Interview Questions

1. What consequences of flow do students experience?

- Please describe your experience in performing the learning tasks using Complete Anatomy. (Q1)
- Please describe if you felt focused or in the zone.

2. What aspects of the 3D virtual tool are distracting to performing the learning tasks?

- How intuitive or cumbersome was Complete Anatomy and why? (Q2)
- Please describe any part of your experience that may have been frustrating. (Q3)

3. How does flow help explain student satisfaction and motivation?

- Please describe how satisfied you were with your experience in using Complete Anatomy in performing your learning tasks. (Q4)
- How did Complete Anatomy motivate you to want to learn anatomy? (Q5)

4. How do students perceive use of the tool to learn anatomy over cadaver-based dissection?

- What are your perceptions of Complete Anatomy as an alternative anatomy dissection tool to human cadavers? **(Q6)**

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