This article explores the effects of the coronavirus disease 2019 (Covid-19) pandemic on the evolution of both physical and digital cadavers within the unique ecosystem of the anatomy laboratory. A physical cadaver is a traditional and established learning tool in anatomy education, whereas a digital cadaver is a relatively recent phenomenon. The Covid-19 pandemic presented a major disturbance and disruption to all levels and types of education, including anatomy education. This article constructs a conceptual metaphor between a typical anatomy laboratory and an ecosystem, and considers the affordances, constraints, and changing roles of physical and digital cadavers within anatomy education through an ecological lens. Adaptation of physical and digital cadavers during the disturbance is analyzed, and the resiliency of digital cadaver technology is recognized. The evolving role of the digital cadaver is considered in terms of increasing accessibility and inclusivity within the anatomy laboratory ecosystem of the future. Anat Sci Educ 14: 399–407. © 2021 American Association for Anatomy.

**Key words:** gross anatomy education; medical education; access to education; Covid-19; curriculum design; digital anatomy; ecology; social inclusion; technology

**INTRODUCTION**

One of the best ways to acquire knowledge about the structure of the human body is to directly interact with it using dissection. Both physical and digital cadavers have been used with the explicit goal of understanding anatomic structures and relationships. The unique strengths of each of these learning tools may have been unexpectedly accentuated during the global Covid-19 pandemic which was declared in March 2020 by the World Health Organization (WHO). As of April 2020, governments worldwide mandated lockdown measures restricting the movement of billions of people (Lenzen et al., 2020). The Covid-19 pandemic disrupted learning by necessitating more than 1,300 institutions of higher education across all 50 states to rapidly transition to remote learning methods (Smalley, 2020). Given these unique circumstances, digital cadavers have been salvation as a learning tool that remained accessible during the pandemic.

Understanding the affordances and limitations of both physical and digital cadavers through an ecological lens is important for pedagogical purposes. An ecological lens provides a holistic perspective of a system as opposed to the evaluation of individual learning tools in isolation (Zhao et al., 2006). The current Covid-19 pandemic-induced changes to anatomy education have stimulated various pedagogic adaptations in order to continue offering anatomy education throughout the disturbance (Evans et al., 2020; Van Nuland et al., 2020; Flynn et al., 2021). These adaptations may be viewed as temporary, although if the past predicts the future, significant periods of social and political change have coincided with long-term curricular changes in science education throughout history (Bybee, 2013; DeBoer, 2019). In this case, the traditional teaching and learning modalities of anatomy education will be permanently altered by this disruption.

This article has two objectives. One objective is to introduce the concept of an ecological framework as a holistic way to examine the effectiveness of technology within anatomy education, specifically the anatomy laboratory. This perspective shifts the analysis from a technocentric focus to a sociocultural perspective (Pacey, 1983). This is done by applying an ecological framework to describe the life cycle of physical and digital cadavers at two periods of time: prior to and during the pandemic. In particular, attention is given to the cadavers in terms
of purpose, adaptation, sustainability, and resilience within the anatomy education ecosystem. An understanding of situational strengths and weaknesses (Zhao et al., 2006) of physical and digital cadavers might provide insight on future best practices for strategic use.

Given the altered functionality of physical and digital cadavers seen during the pandemic, the second objective of this analysis is to speculate about ways to increase accessibility and inclusivity of anatomy education in a post-pandemic setting. Although the goal to increase accessibility and inclusivity within education is not new (Dimick, 2012; Collin, 2013; Brown and Au, 2014), the Covid-19 pandemic (i.e., a unique, historical time period) provided an impetus for anatomy educators to design learning experiences that are more accessible in an immediate sense, and some of these innovations included the use of digital cadavers (Flynn et al., 2021; Iwanaga et al., 2021; Naidoo et al., 2021). As such, will the pandemic, a biologic event, and disruption in the anatomy education ecosystem, drive the evolutionary path of digital cadavers? Can this unique point in time help educators identify ways to make anatomy education more accessible and therefore more inclusive for a broader group of students, or is the anatomy laboratory ecosystem destined to simply return to pre-pandemic business as usual?

The article starts by introducing an ecological framework as a way to conceptualize a complex, interactive system using fundamental ecological concepts and terminology (Zhao and Frank, 2003). This conceptual framework is first described in terms of biology. It is then used to construct a conceptual metaphor with the anatomy laboratory. The pre-pandemic life cycles of physical and digital cadavers are explored in terms of purpose and then pandemic induced adaptations in anatomy education are considered, focusing on functionality gained and lost. Last, attention is given to the vulnerabilities of our current anatomy education ecosystem, and how mindful planning might help guide the development of future anatomy education resources and pedagogic practices that are more accessible, resilient, and widespread.

CONCEPTUAL FRAMEWORK

An Ecosystem is a Holistic System of Interactions

An ecosystem can be thought of as a dynamic community filled with system-wide interactions that occur among the biotic and abiotic components of the system. Biotic components are the living elements of the community such as people, plants, and animals. Abiotic components of the community are non-living elements, such as the physical location and resources (Jørgensen, 2009). The biotic component of an ecosystem has numerous species, each of which plays a unique role within the ecosystem. Species that exert control over the ecosystem are known as keystone species (Power et al., 1996; Garibaldi and Turner, 2004). Ecosystems can be small (e.g., fish tank) or large (e.g., ocean), but are always complex systems due to the number of interacting components. Ecosystems are holistic systems that strive to establish a balance among the members of their community and their environment, a dynamic state known as equilibrium (DeAngelis and Waterhouse, 1987). Due to the continually changing conditions, ecosystems are susceptible to disturbances, such as a change in community members (e.g., additional or less members, illness, changing needs of members), change in the environment (e.g., change in available resources), or a change in interactions among the species (Rykiel, 1985). The ability of an ecosystem to maintain equilibrium has to do with its resistance to disturbance and its resilience during and following a disturbance (Holling, 1973; Stone et al., 1996).

An ecological conceptual framework has been used by researchers for different types of dynamic systems, such as the introduction of technology into a particular educational setting (Zhao and Frank, 2003; Zhao et al., 2006). This premise has also been theorized as an ecosocial system, a specified ecosystem consisting of a human community interacting within a physical setting that supports and limits interactions between people and materials (Lemke, 1993). The use of this conceptual framework involves applying defined components of an ecosystem (i.e., biotic components, abiotic components) to a new setting. It also applies knowledge about interactions that occur within an ecosystem to the new setting, for explanation or prediction purposes (Zhao and Frank, 2003). It is in this way that a metaphor is established between an ecosystem and a new system under study.

Like an ecosystem, anatomy education is a complex system. One component of this system is the anatomy laboratory, which contains multiple populations of interacting species that have various roles as stakeholders within the setting. These interacting populations include students, teaching assistants, instructors, laboratory managers, maintenance services, and administrators. The setting will likely consist of workspaces for students and the instructor, as well as the equipment, specimens, and models that are used during laboratory sessions. An anatomy laboratory is nested within a hierarchy, like any ecosystem. An anatomy laboratory is one component of a department housed within a college, which in turn is networked within the larger system of higher education that serves various professions. Like all ecosystems, the anatomy laboratory will strive for a state of equilibrium where it is functioning as a productive teaching and learning environment without disruption or disturbance from within or externally.

Viewing an anatomy laboratory as an ecosystem emphasizes the complex interactions that take place between the biotic and abiotic components within this specialized community. It takes into account that both humans and technology adapt and take an evolutionary path (Basalla, 1988). Survival of technology within an ecosystem is not a simple matter of success or failure, but an amalgamation of human perceptions of value, digital evolution, continuous adaptation, and mutual adjustment of biotic and abiotic members of the community to each other (Waight and Abd-El-Khalick, 2018).

In an effort to further establish an anatomy laboratory as an ecosystem, the metaphorical equivalents established by Zhao and Frank (2003) are used: teachers as keystone species, physical cadavers as a native species, and newer digital cadavers as an invading species. The subsequent subsections describe each of these species in greater detail.

Instructors and Students as Distinct Species

A keystone species is a less abundant population that exerts control within a system (Garibaldi and Turner, 2004). Keystone species are not the dominant species, yet their influence within the system is much greater than can be predicted by their abundance. Instructors in the anatomy laboratory ecosystem are keystone species exerting control as strategists and stakeholders. The instructor(s) determine the pedagogy by planning, overseeing, participating in, and assessing the activities.
Students make up the dominant species and they also exert control by actively participating in the activities of the laboratory. Students and instructors have extensive interactions within the ecosystem. For example, during a typical laboratory session, the instructor might provide the goals, demonstrate the use of tools and materials, and provide instruction about the foundational knowledge needed to accomplish the learning objectives. The instructor might interact with students by presenting to the class, leading class discussions, and addressing individual student questions and issues. These interactions directly promote the accomplishment of student learning outcomes and also facilitate the development of nontraditional discipline-independent skills (NTDIS). These NTDIS such as collaboration, leadership, and professional characteristics (e.g., respect, integrity, responsiveness, accountability) have long been part of the hidden curriculum of the anatomy laboratory (Kumar Ghosh and Kumar, 2019).

The development of NTDIS is essential within the anatomy laboratory ecosystem because NTDIS bridge academic conduct with the professional ethos needed for future service in the healthcare industry (Evans and Pawlina, 2020). The interactions between and among these two species are complex and potentially even foreign to people outside of that specific ecosystem (Ihde, 2009). This is because interactions within the anatomy laboratory are highly specialized and involve precise tools, vernacular, equipment, models, concepts, and mutually constructed understandings (Lemke, 1990; Latour, 2009; Latour and Woolgar, 2013).

Physical Cadavers as Native Species

Physical cadavers have been part of the standard paradigm of anatomy teaching and learning for hundreds of years. Traditionally, three-dimensional (3D) exploration of the human body was done with physical cadaver dissection, long considered the centerpiece of anatomy education (McCachlan and Patten, 2006). Physical cadaver dissection remains a common learning experience in anatomy education (Memon, 2018; Ross et al., 2021). It is still considered by many to be the defining experience of a medical student today (Kerby et al., 2011). One reason for the success of the physical cadaver is that physical dissection offers numerous unique advantages to the learner. It is a tactile, authentic way to learn anatomic structures in ways not otherwise possible (Willan and Humpherson, 1999; Iwanaga et al., 2021).

Perhaps there is irony in considering a lifeless physical cadaver a living native species within the anatomy laboratory ecosystem. But one can argue that once human life leaves its physical vessel, it is possible for the lifeless corpse to take on a new and purposeful trajectory, in other words, a new life form. There are many examples of physical cadavers as living species within medicine, research, art, and education ecosystems. Medical uses of cadavers range from harvesting organs for transplantation to practicing surgical techniques (Gilbody et al., 2011; Thamphongsri et al., 2017). Cadaver research includes motor vehicle accident assessment and decomposition studies that inform forensic investigations (Shirley et al., 2011; Yoganandan et al., 2015). Cadavers can be transformed by plastination into durable and art-like models for educational and artistic purposes (Kurt et al., 2013). The potential second life of a physical cadaver is extensive; and can be viewed as a gift to the living. This article focuses on the use of a preserved human body for dissection in the anatomy laboratory.

The automatic artifact of human life, the human cadaver, can be considered analogous to a living species in the anatomy laboratory ecosystem because they interact with other species within their environment, and they fulfill a community’s needs. Physical cadavers reveal anatomic relationships, anomalies, variations, and textures in tactile, tangible ways that are not readily available otherwise in the laboratory (Granger, 2004). Also, physical cadaver uses have continuously evolved over time into different forms to realize different functions (Ghosh, 2015), for example, using individual body parts (e.g., joint, brain, individual organ) for specific learning goals. This is the same trajectory observed for other living species (Bennett, 2017). And, like other native species, cadavers can be challenged by competition within the ecosystem (Saltarelli et al., 2014). There are many competitors for time and attention in the anatomy laboratory ecosystem such as physical models and digital cadavers.

Digital Cadavers as Invading Species

A common belief about the purpose of technology is that it will solve a problem (Basalla, 1988; Heidegger, 2009). Human reliance on technology to solve problems is well established in human history (Illich, 1973; Voltt, 2005). A digital cadaver was originally conceived by the National Library of Medicine (Bethesda, MD) to establish a library of digital images of the human body (Spitzer and Whitlock, 1998). The resulting Visible Human Project (VHP) was intended to serve the increasing demand for digital human body images in clinical medicine and biomedical research (Lindberg and Riecken, 1986; NLM, 2021). The VHP set out to build a complete anatomic data set and images for a complete adult male and female digital cadaver (Preim and Saalfeld, 2018). The male anatomy was published in 1994, followed by the female data sets in 1995 (Spitzer and Whitlock, 1998). These technological advances diffused globally and resulted in an international effort to increase the diversity of available data sets (i.e., populations other than Caucasian). The Visible Korean Human (VKH) project refined the data acquisition techniques that were used in the VHP and generated human representations with realistic color (Park et al., 2005, 2006). Subsequent technologic improvements made by the Chinese Visible Human (CVH) project improved the visualization of small areas and blood vessels and resulted in male and female data sets based on an Asian population (Zhang et al., 2003, 2004).

From an evolutionary standpoint, the VHP can be viewed as the origin of digital cadavers, paving the way for the creation of interactive digital cadavers (Trelease, 2016; Preim and Saalfeld, 2018). These new digital tools in anatomy education have emerged from a long and historic antecedent system of physical model use and physical cadaver dissection, as is commonly seen in the evolution of technology (Basalla, 1988; Maerker, 2013). The initial introduction of digital cadavers into the anatomy laboratory environment may be due to the basic human desire to accomplish work better, faster, and more efficiently (Basalla, 1988; Voltt, 2005; Tenner, 2018). Ultimately, many factors will determine the success or failure of the digital cadaver within anatomy education.

New digital technologies such as an interactive digital cadaver have the characteristics of an invading species. Invasive species are newcomers to the environment, they are not native species (di Castri, 1990). This is true of the relatively recent introduction of digital cadavers in the anatomy laboratory ecosystem.
(Trelease, 2016). Digital cadaver technology ranges from an interactive 3D model contained on a two-dimensional (2D) screen to holographic models (Preim and Saalfeld, 2018). Screen bound digital cadavers, also known as 3D visual technology (3DVT) (Yammine and Violato, 2015) are both freely available (e.g., Zygote Body; Zygote Media Group Inc., American Fork, UT) and proprietary (e.g., Primal Pictures; Primal Pictures Ltd., London, UK), Visible Body (Argosy Publishing Inc., Newton, MA). Some types of 3DVT are functional on mobile screens (e.g., phone, laptop) while others, such as dissection tables are less mobile (e.g., Anatomage, Anatomage Inc., Santa Clara, CA). Holographic digital cadavers are integrated into augmented reality (i.e., includes both virtual and real elements) and virtual reality (i.e., fully immersive environment requiring head-mounted hardware) platforms. Although all types of digital cadavers can be considered invading species, this analysis focuses on 3DVT digital cadaver technology that is accessed using common electronic devices such as a computer, mobile phone, or a tablet.

Like any invading species, digital cadavers have the potential to threaten the equilibrium of the invaded ecosystem by competing with or even replacing the native species, physical cadavers. This competition could be for space in the physical environment, time to interact with the dominant and keystone species (i.e., students and instructors), or even money to support the life of the invasive species at the expense of the native species (e.g., having to determine how a fixed laboratory budget will be allocated among various expenses). Invasive species are often introduced into new environments through human activities, as is the case for digital cadavers (Trelease, 2008; Traser et al., 2015).

The increased availability of digital cadavers has partially fueled a trend in anatomy education to incorporate digital cadavers into the curriculum, either as a supplement or replacement to traditional learning tools such as plastic models and physical cadavers (Breton et al., 2007; Drake et al., 2009; Lewis et al., 2014; Estai and Bunt, 2016; Trelease, 2016; Moro et al., 2017). As commonly seen in an ecosystem, existing species can be displaced by invading species (Vanderploeg et al., 2002). What this means in the anatomy laboratory ecosystem is that physical cadaver use might change due to the introduction of digital cadavers into the system. Physical and digital cadavers have different strengths and limitations, so the survival of the invading species depends on its characteristics and its interactions with the native and keystone species (Rodriguez, 2006). The Covid-19 pandemic has been a major disruption in the anatomy laboratory ecosystem that has highlighted the strengths of easily accessible digital cadavers while simultaneously accentuating the limitations of laboratory bound physical cadavers.

**LIFE CYCLE ANALYSIS**

**Pre-Pandemic Coexistence and Mutuality of Physical and Digital Cadavers**

Both physical and digital cadavers have been utilized in anatomy laboratories for decades, they are not mutually exclusive learning modalities. Since no one curricular material or experience will be effective for all types of students, cultures, or learning objectives, it makes sense for physical and digital cadavers to coexist and evolve (Ghosh, 2017). Anatomical studies require three dimensional, spatial considerations (Langlois et al., 2015). Both physical and digital cadavers provide a means for this type of visual and spatial experience (Berney et al., 2015). The addition of digital cadavers into the anatomy laboratory ecosystem has been shown to increase student learning when combined with more traditional learning methods (Peterson and Mlynarczyk, 2016). Both physical and digital cadavers can facilitate authentic learning experiences that increase student agency because students strategically determine how to best interact with the specimen, whether that specimen be physical or digital (Bandura, 1982; Ci, 2011; Arnold and Clarke, 2014; Bandura, 2018).

**Global Disruption: Predator-Prey Interactions in the Anatomy Laboratory**

In March 2020, the Covid-19 pandemic suddenly and severely disrupted the culture of learning within the anatomy laboratory ecosystem. Viewed through an ecological lens, this disruption was caused by viral predation. A virus is an effective predator of humans for many reasons. Viruses are invisible, ubiquitous, non-living, submicroscopic parasitic agents. They continually evolve via genetic diversification (Crawford, 2002). Alternatively, the defense mechanisms of a human also continually evolve, making the relationship between the two analogous to a predator-prey relationship (Voskarides et al., 2018). The predator-prey relationship is one that drives evolutionary change through adaptation and the premise of survival via the perpetuation of successful traits (Abatecola et al., 2016).

Even though the disruption caused by the Covid-19 pandemic was due to human vulnerability, abiotic populations within the anatomy laboratory ecosystem are also susceptible to disturbance, including viral infection. Viruses that prey on technical (i.e., abiotic) devices are simply pieces of code, harmful and quiescent while separate from a host. Just like viruses that attack humans, a computer virus also needs to infect a host to function (Joshi and Patil, 2012).

The consequences of predation within an ecosystem typically lead to behavioral and social adaptations within the system (Isbell, 1994). In the case of the anatomy laboratory ecosystem, it was these behavioral adaptations (i.e., social distancing) and social adaptations (i.e., transition to remote learning) that significantly changed the culture of the community.

**Adaptation and Survival of the Fit Enough**

Despite the disruption, the need for anatomy education remained unchanged during the pandemic. Therefore, adaptation to the changing environment was unavoidable. Major physical accessibility restrictions were instituted in education, resulting in a shift to virtual learning modalities (Blankenburg et al., 2020; Evans et al., 2020). The education system did not have a preparedness plan for this rapid transition to remote learning, causing many challenges within anatomy education (Johnson et al., 2020; Van Nuland et al., 2020).

Two adaptations resulting from the pandemic were limiting human access to various physical environments and social distancing protocols (Courtemanche et al., 2020). These practices prevented large-scale anatomy laboratory activities to continue as usual. Since physical cadaver dissection cannot be performed remotely, the coexistence and mutuality of physical and digital cadavers were disrupted. This triggered a shift in pedagogic practices from traditional physical laboratory activities to the use of remote digital tools such as digital cadavers (Cuschieri and Calleja Agius, 2020; Franchi, 2020; Van Nuland et al., 2020).

The Covid-19 pandemic exposed a human vulnerability that was a weakness in the anatomy laboratory ecosystem: the need for physical gatherings within the laboratory (e.g., instruction, student study groups, demonstration). The native
species (i.e., physical cadaver) is bound to a physical laboratory setting. The limited accessibility of the native species (i.e., you must physically be with the specimen to participate in an activity, the cadaver is not readily mobile and not easily accessible via video conferencing applications) is not new, but combined with the new social adaptations, access to physical cadavers became severely limited. This in turn increased the value of digital resources, including digital cadavers. Whether this trend is temporary or longer lasting is unknown (Evans et al., 2020; Khazan, 2020; Srinivasan, 2020).

A potential consequence of this adaptation is the inability to accomplish certain learning goals that rely on or are best achieved using the native species (Franchi, 2020; Jones, 2020). Advantages of physical cadaver use from educator and student perspectives have been well documented in the literature. Although physical cadaver use is not universally required or even preferred by all educators (McMenamin et al., 2018), it is credited with many humanistic benefits, such as assisting the student development of NTDIS (Warner and Rizzolo, 2006; Kumar Ghosh and Kumar, 2019; Evans and Pawlina, 2020). Physical cadaver dissection can be an emotional experience for a student because a physical cadaver, unlike a digital cadaver, was once a living person. This experience humanizes the study of anatomy in a way that a digital recreation cannot (Barash et al., 2021). The relationship between the student and physical cadaver mirrors the future relationship between the health care professional and the patient (Evans et al., 2018). Therefore, this relationship is governed by principles of respect, confidentiality, and dignity (Jones, 2020). The donor is considered by many students as their first patient, gratitude traditionally being expressed through a memorial service at the conclusion of the laboratory course (Jones et al., 2014).

Despite the unique benefits of physical cadavers, many schools had eliminated physical cadaver use prior to the pandemic, in favor of the more technical interfaces of the invading species (i.e., digital cadaver) (Sugand et al., 2010). Reasons for this trend likely include a multitude of factors such as an effort to overcome challenges posed by physical cadaver use (de Craemer, 1994; McLachlan et al., 2004; Drake et al., 2009; Alvord, 2013; Preim and Saalfeld, 2018), along with the ubiquitous nature of technology and increased availability of digital cadavers (Sugand et al., 2010; Trelease, 2016; Preim and Saalfeld, 2018).

A 3DVT digital cadaver has some unique advantages over a physical cadaver because it can be accessed using common electronic devices such as a computer, mobile phone, or a tablet. 3DVT digital cadaver technology does not require specialized devices such as a touchscreen dissection table or a head-mounted display, which makes it more accessible than virtual dissection tables and virtual reality platforms. In addition to remote availability, there are countless viewing options, use is nondestructive in nature, and a digital cadaver is not opposed by religious beliefs (Estai and Bunt, 2016). There is some evidence that digital cadaver use improves student performance by improving student spatial abilities (Guimarães et al., 2019), improving factual and spatial knowledge acquisition (Yammine and Violato, 2015), and increasing user satisfaction (Darras et al., 2019; Jamil et al., 2019; Triepels et al., 2020). Digital cadavers are credited with increased learning when the user exerts control over the experience rather than observation alone (Jang et al., 2017). Although promising, these findings are not consistent within the literature (Lombardi et al., 2014; Azer and Azer, 2016; Yammine and Violato, 2016; Wainnan et al., 2018). Nonetheless, a digital cadaver provides a non-threatening learning environment, a factor shown to positively affect learning (Turner and Harder, 2018).

The invading species have also posed challenges within the ecosystem that have human, technical, and socioeconomic origins. The need for a fully functional visual system in both eyes in order to interpret the 3D effect in 3DVT will exclude some learners (Tommil, 1974; Wainman et al., 2020). The learner’s spatial ability has also been shown to determine the effectiveness of 3DVT, with digital cadavers’ best-serving students with high spatial ability (Garg et al., 2001; Levinson et al., 2007). Numerous empirical studies have consistently documented biological sex differences in spatial ability with males consistently outperforming females (Barel and Tzischinsky, 2018; Guimarães et al., 2019). Since many types of digital cadavers exist, there is also the need for the educator or student to choose the tool. This sets up a potential misalignment between learning tools and learning objectives (Van Nuland et al., 2020). The time and effort spent learning how to utilize and navigate digital cadaver software do not necessarily contribute to learning the course content (Van Merriënboer and Sweller, 2010). The authenticity of the visual representation of some digital cadavers has also been criticized because of the lack of realistic visual representation (e.g., fascia, anomaly, texture) and the lack of tactile sensation. And of course, in order to potentially benefit from a digital cadaver, access is necessary. This requires access to software, hardware, and internet connection services which could be significant obstacles (Jones, 2020).

Availability versus nonavailability may be the single dominant trait of the invading species driving its success in an environment with limited interpersonal interactions. The affordances of digital cadavers could serve to promote the use of this methodology on a broader scale in a post-pandemic ecosystem (Mhlanga and Moloi, 2020; Srinivasan, 2020). One potential benefit of this is that a digital cadaver has the potential to increase accessibility for learners that lack access to physical cadaver dissection (e.g., community college students, undergraduates, lack of donor bodies). A digital cadaver can provide academic support to all students outside the physical setting of the laboratory. Although the potential for digital cadavers to increase accessibility existed prior to the pandemic, the increased cultural value of digital cadavers seen during the pandemic could positively affect the evolution of digital cadavers within the anatomy laboratory ecosystem in the future.

A central premise of evolution is survival of the fit enough, and currently, digital resources are dominating the landscape of the anatomy laboratory ecosystem due to the rapid transition to remote learning in higher education. Although it makes sense to rely on digital cadavers for the short term, time will tell whether this trend continues post-pandemic, or whether the affordances provided by physical cadavers will bring them back to the laboratory to once again coexist with their digital spawn. Analysis using an ecological perspective suggests that traditional teaching approaches and learning modalities will be altered permanently with the Covid-19 induced shift.

**DISCUSSION**

**Vulnerability Exists Within the Ecosystem of the Anatomy Laboratory**

The Covid-19 pandemic has exposed human vulnerability within the anatomy laboratory ecosystem. Through this disruption to the system, new patterns of behavior have emerged (i.e., limiting the number of people present in a laboratory, classroom, facility, and college; transition to online learning). Although these behaviors are directly intended to reduce the
risk posed to the keystone and dominant species, they have created other challenges such as accomplishing all of the learning goals without physical access to a laboratory (Iwanaga et al., 2021). Human vulnerability to viral infection has driven a paradigm shift in the anatomy laboratory ecosystem from the native to the invading species.

It makes sense for future anatomy laboratory ecosystems to incorporate both physical and digital cadavers, since both techniques offer unique advantages and neither method is immune from disruption. The Covid-19 pandemic affected the practice of physical cadaver use, but digital cadavers are also susceptible to viruses. Malware has the potential to disrupt an ecosystem that is heavily or solely dependent on digital cadavers, as do power outages and other forms of infrastructure failure. Ideally, the anatomy laboratory ecosystem needs to be prepared for possible future disruption to either biotic or abiotic members of the community.

Opportunity to Evolve Toward a More Inclusive and Sustainable Curriculum

A primary purpose of anatomy education is to serve the health care industry. Graduates from academic programs such as medicine, nursing, and allied health fields will help to fulfill the general population’s growing need for healthcare. As the anatomy laboratory ecosystem evolves and adapts, it must be acknowledged that the health care industry is also rapidly evolving. The pandemic has stimulated changes in the way health care is delivered. One example is the shift to telemedicine rather than traditional face-to-face visits in a doctor’s office (Sansom-Daly and Bradford, 2020). The healthcare industry, like anatomy education, had been increasing its reliance on digital technology prior to the pandemic. For example, robotic surgery was first conceived decades ago (Pugin et al., 2011), but has evolved over the years to enable surgical procedures, treatments, and diagnoses that were traditionally hands-on to be accomplished without the assistance of direct human contact (Avgousti et al., 2016).

Given the increased use of technology to deliver health care, perhaps now is the time to shift the culture of the anatomy laboratory ecosystem as well. A holistic ecological analysis of the life cycles of physical and digital cadavers reveals opposite trending patterns. Prior to the pandemic, the use of the native species (i.e., physical cadaver) was trending downward (Sugand et al., 2010), a trend that was exaggerated during the pandemic due to social adaptations (Flynn et al., 2021). Alternatively, the invading species were in a state of growth prior to the pandemic (Trelease, 2016) and have continued to trend upwards during the pandemic (Harmon et al., 2021). One benefit of using an ecological framework for analyzing technology within a culture is that it highlights the fact that the system is functioning as a whole, adapting to changing needs and conditions. The affordances and constraints of individual species within this complex ecosystem do not entirely determine their future. Based on the sustainability that the digital cadaver has demonstrated during the pandemic, it makes sense to speculate whether or not this technology could help address other challenges within the anatomy laboratory ecosystem or even facilitate desired change (Bogomolova et al., 2021; Das and Mushaigri, 2021; Evans and Pawlina, 2021; Evans, 2021).

In order to create a more sustainable and stable ecosystem for anatomy education, technology must be considered both an artifact and a process (Waigh and Abd-El-Kahlick, 2018). Given that digital cadavers have sustained existence through a situational disruption (i.e., pandemic), perhaps digital cadavers could also increase access to anatomy education under various cultural circumstances. Since there is an ethical obligation for educators to work toward making necessary resources available to students and faculty at a global level (Brown, 2019; Jones, 2020), increased access to digital cadaver technology might help anatomy education reach a broader student population, assisting students who traditionally lack access to physical cadavers. For example, by increasing access to students in disadvantaged countries, community college students, and students from all levels of socioeconomic status. The effectiveness of digital resources has been shown to span across varying socioeconomic levels (Kononowicz et al., 2019). Increased access to digital cadavers could also assist students with variable amounts of academic preparedness and students challenged with disability. Digital resources align with the way students ordinarily obtain information (Garoufallou et al., 2016). Digital resources can permit users to control operational speed and give immediate feedback (Cranmer, 2020). One proposed solution to address a diverse student population is the use of flexible instructional media and technology (Rose and Meyer, 2002; Tobin and Behling, 2018).

If a digital cadaver is considered as a process in addition to an artifact, other aspects of the ecosystem must also be considered such as the source of the software (Franchi, 2020; Das and Mushaigri, 2021), access to adequate devices (Pacheco et al., 2020), and access to a sufficient internet connection (Jones, 2020). Unless the holistic system is taken into consideration, increased reliance on digital cadavers within the anatomy laboratory ecosystem also has the potential to accentuate inequity issues (Jones, 2020; Naidoo et al., 2021).

Another consideration is whether digital cadavers could be used to increase social inclusivity by visually representing diverse student populations (e.g., racial, ethnic, and gender diversity). Research findings show biased visual representation in anatomy textbooks and strict adherence to binary sex (Parker et al., 2017). This lack of neutrality can unintentionally reinforce socially constructed stereotypes (Morgan et al., 2014). As equity and diversity issues become increasingly important in education, a more inclusive human representation in the anatomy laboratory ecosystem is necessary (Štrkalj and Pather, 2021). Digital technology has the capability to integrate multiple representations (e.g., age, sex) compared to traditional technology, such as a single physical cadaver or even a static image printed on a 2D page. Visual tools also have the potential to mediate language differences (Nedungadi et al., 2018).

Last, since one of the advantages of the digital cadaver is its availability outside the walls of the physical anatomy laboratory, educators need to design experiences that provide guidance for independent study. In addition, digital cadavers could possibly play a role in skill acquisition and assessment. Continued development of digital cadaver pedagogy that integrates interactive experiences with measurable learning goals would benefit students (Franchi, 2020). Learner-centered experiences that include active participation with a digital cadaver have been shown to be more effective than observation alone (Jang et al., 2017). This is in contrast to utilizing a digital cadaver as a reference (e.g., supplemental resource) or passive use that is observational in nature (e.g., video). Another consideration is how digital cadavers could potentially be used to incorporate NTDIS which are typically learned face-to-face. Early research shows that digital cadaver technology may be an effective communication tool for the purpose of patient education (Lam et al., 2018). Perhaps technical skills acquired with a digital cadaver could serve to strengthen communication skills with future patients. In addition, as anatomy education evolves,
assessments should evolve in a parallel manner (Langlois et al., 2017; Evans, 2021). That could involve digital cadaver integration into assessment tools (Bogomolova et al., 2021). These types of advances will assist educators to purposefully integrate digital cadavers into the curriculum.

It is the role of anatomy educators to honor and support student learning by cultivating an inclusive environment for anatomy education (Shea and Sandoval, 2020; Smith and Pawlina, 2021). The question is not about whether physical or digital cadavers are superior, but instead a question about how to best utilize the merits provided by each (Singh and Kharb, 2013), in an effort to positively influence the continued evolution of the anatomy laboratory ecosystem. Although digital resource use has increased as a result of the pandemic, it is important that continued technology use within the ecosystem offers the same or better learning outcomes than traditional learning tools (Evans et al., 2020). The Covid-19 pandemic has forced educators to re-evaluate how existing curricular resources can be made more sustainable. Digital cadaver technology has the potential to transform the nature of anatomical educational experiences and the future culture of the anatomy laboratory ecosystem.

Limitations of the Study

This study uses a conceptual ecologic framework, which is a valuable tool for examining interactions within a holistic system, such as an anatomy laboratory. Although this framework has been utilized successfully for analyzing and making sense of complex systems involving technology and education in the past (Waite and Abd-El-Khalek, 2018), no metaphor is perfect. Inconsistency between target and source meanings will exist at various levels (Taylor and Dewsbury, 2018). Also, metaphors can be viewed as exclusionary because they function by utilizing “shared understandings,” drawing a parallel between more defined and less familiar scenarios (Larson, 2011). Last, metaphor alone does not adequately predict the future of a complex, dynamic situation like an anatomy laboratory or represent all stakeholders. The intent of the ecosystem metaphor used in this article was to highlight interactions and adaptations within a situational context, and to use the premise of evolution to speculate about the future trajectory of digital cadavers in anatomy education. Future empirical findings will reveal if and how the Covid-19 pandemic affected the evolution of digital cadaver pedagogy.

CONCLUSIONS

Using an ecological framework, it can be established that adaptations made during the Covid-19 pandemic have the potential to permanently alter the culture of the anatomy laboratory ecosystem. Given these circumstances, it makes sense for educators to strategically and deliberately plan for the future rather than simply returning to the status quo. The Covid-19 pandemic has given educators unique circumstances to consider the purposeful construction of more resilient and inclusive anatomy education resources for the future. The digital cadaver is one learning tool that has proven to be resilient in times of disturbance. It also has the potential to make anatomy education more accessible and inclusive in the future.

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NOTES ON CONTRIBUTOR

YVONNE M. BAPTISTE, M.S., is a professor of biology in the Division of Science, Health, and Mathematics at Niagara County Community College in Sanborn, New York. She is also a doctoral candidate in the Curriculum, Instruction, and the Science of Learning PhD Program at the State University of New York at Buffalo, Buffalo, New York. Her interests include conceptualizing and creating multimedia curricular resources for anatomy education such as interactive software, video, and dissection photography.

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