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Cases on Instructional Design and Performance Outcomes in Medical Education

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Chapter 5
Virtual Reality Stereoscopic 180-Degree Video-Based Immersive Environments:
Applications for Training Surgeons and Other Medical Professionals

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EXECUTIVE SUMMARY

The theoretical and practical applications of immersive VR, although relatively new, have accomplished much in the area of pedagogical learner applications. This chapter describes the conceptual framework and Revinax® 180-degree stereoscopic video-based approach in addressing the academic achievement gap through conventional surgical students and nurses shadowing and how immersive VR environments may best address leveraging the learner's capability of increasing their skill acquisition, learning, and knowledge retention in a more efficient time-period, circumventing the inherent issues with conventional shadowing. Further, these VR experiences through

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first-person Point of View (POV), although simulated and artificial, evoke mirror neurons, and can recruit neurocircuitry that are imperative for skill acquisition and later skill application. As such, the Revinax® instructional design model may provide a unique insight in how to use immersive VR environments to teach any learner that seeks to acquire surgical/medical professional training more efficiently and practically in a modern world of technology.

INTRODUCTION

New technological programs, tools, and devices often create excitement and curiosity as people seek to learn about new technologies and their potential future applications. This is especially true for individuals that given their specific job/training roles, could find ways in which technology can help them complete their work more effectively and efficiently. Thus, it is not surprising that many educators and future generation learners are currently increasingly exposed to pedagogical approaches targeted at technology-dependent learning instruction over conventional approaches. Such modern pedagogical technology-dependent approaches have already begun, yet as many emerge, a clearer understanding of their utility, generalization, and translational application(s) from the learning environment into real-world contexts, become the greatest sought after outcome measure. Further, some of these technology-dependent applications may be less educationally immersive (*e.g.,* avatar simulations, 2-D video simulations, passive video recording instruction, etc.), while others can be more educationally immersive (*e.g.,* virtual reality [VR], stereoscopic first-person point-of-view [POV] instruction, etc.). Therefore, during such a technologically expansive, exciting, and necessary time-period, educators are seeking novel and effective approaches for elucidating which technological programs, tools, and devices would be best suited for their pedagogy is warranted. In order to shed light on this very issue, the present study offers an unbiased assessment of how VR can be used in novel evidence-based ways for assessing educational training of surgeons and other medical professionals.

As such, VR has evolved significantly from its inception in the 1950s (*For Review See* Mandal, 2013) and is presently emerging as a versatile pedagogical tool that can be used to train surgeons more effectively and efficiently across a number of medical interventions (Alaker, Wynn & Arulampalam, 2016; Vaughn, Dubey, Wainwright & Middleton, 2016; Aim, Lonjon, Hannouche & Nizard, 2015; Ragan et al., 2015; Anderson, Winding & Vesterby, 2011; Gurusamy, Aggarwal, Palanivelu & Davidson, 2008; Aggarwal et al., 2007; Haque and Srinivasan, 2006). Despite the fact that VR encompasses a wide range of user experiences that are appropriate for different training objectives and applications, it has also been shown to have an increasing demand and interest in the educational training of more medical applications (Kamińska et al., 2019; Górski, Bun, Wichniarek, Zawadzki & Hamrol, 2017;). Consistent with these current trends, Revinax® has uniquely integrated VR technology with the use of a stereoscopic 180-degree video-based intervention to provide surgeons and other medical professionals with a first-person POV of the surgical procedures that they will be trained on, in addition to accessing other relevant patient data as part of the curriculum for a surgical training program. The goal of this surgical training program was to: 1) provide video-based evidence of the value of stereoscopic 180-degree VR; 2) establish the importance of its technological and curricular design; 3) discuss what the field can learn from modeling, validating, reliably testing, and/or building upon such pedagogical technologies; and 4) how such technology can be effectively used for educating medical students and professional on surgical interventions through more immersive experiences.

WHAT IS VIRTUAL REALITY (VR)?

There are many definitions of VR, partly because of the wide range in which it is executed in order to achieve the context-specific goals of the design team. Some current examples of VR definitions are: creating digital worlds/environments suitable for real-time human learning (Górski, Bun, Wichniarek, Zawadzki & Hamrol, 2017), an environment for users to interact with artificial stimuli in a somewhat naturalistic way (Concannon, Esmail & Roduta-Roberts, 2019), "an artificial three-dimensional environment…presented to a person in an interactive way" (Kamińska et al., 2019, p. 2), and as an environment which promotes immersion, interactivity and imagination (Concannon et al., 2019; Kamińska et al., 2019). These VR definitions provide the theoretical framework from which pedagogical instructional designers can begin to envision the kinds of artificial, somewhat naturalistic, and immersive environments that they would like to create as part of their curriculum. Further, the exact time-points or active learning opportunities that they envision, can then be pre-determined within these VR environments to control and investigate through evidence-based means, how the student users' interactivity within and responsivity to the VR environment can be investigated. This latter point is pivotal since the instructional design of VR environments have varying levels of user immersion, and without such proper instructional design intention and controls in place, identifying an evidence-based pedagogical approach through VR would be obscure. Arguably, the levels of user immersion within the VR environment, directly relates to whether or not a user can experience aspects of the VR environment that will facilitate them in obtaining a simulated sensory experience of the real-world (Concannon et al., 2019). Moreover, the levels of immersion experienced by the user directly affects how *"actively present"* the user feels within the VR experience (Górski et al., 2017). Kamińska et al. (2019) notes that the *"level"* of immersion that the user experiences should be adjusted based upon the curricular training goals with the lowest-level of immersion being used for knowledge acquisition (*i.e.,* the short-term learning objective), a moderate-level for skills acquisition (*i.e.,* sustained learning acquisition and skills maintenance), and a high-level of immersion for problem solving (*i.e.,* applied learning, contextual (re)organization, and generalization of skills learned from one environment to another). According to Fowler et al. (2015) the most important factors that are used as criteria to obtain a successful 3D VR learning environment/experience for the user are: 1) presence (*i.e.,* the user feels as if he or she were within the environment), 2) co-presence (*i.e.,* the user feels as if other people were within the environment), and 3) interactivity (i.e., the user feels as if they can manipulate, explore, or become apart of the environment). Thus, immersive VR (*i.e.,* accompanied by a headset otherwise referred to a head mount display [HMD]) can achieve and/or fulfill all of these factors, thereby meeting the criteria for an effective and user optimized 3D VR learning environment/experience.

Indeed, beyond immersion-dependent learning processes, an equally important instructional design feature of VR environments are the varying levels of interactivity that provide opportunities for how the user and their (in)actions can relate to how the users can manipulate the VR environment (Concannon et al., 2019). Some examples of interactivity are input devices that can include motion-sensing gloves, controllers or photo sensors that allow the user to see and use their hands within the VR environment (Concannon et al., 2019; Górski et al., 2017). Some VR environments also provide haptic (*i.e.,* tactile vibration-dependent sensory reception or proprioception) feedback or resistance to simulate an immersive sensory experience (Concannon et al., 2019; Górski et al., 2017). The amount of control that a user has within the VR environment can directly influence how *"real"* the experience is perceived and whether or not the user feels *"present"* within the VR environment (Concannon et al., 2019). Notably, how closely "the user's actions, senses and thought processes…resemble those that would be experienced while in the same situation…in the real world" (Concannon et al., 2019, p. 4) is known as fidelity (*i.e.,* influence of believing the *"realness"* of such VR environments). It is imperative that the physical, functional, and psychological fidelity of the VR environments in which the users experience be examined separately to address where the instructional design and curricular content provide the most interactivity for the user to achieve an optimal and believable learning outcome (Concannon et al., 2019). This would promote the user's perception of a high fidelity VR environment that would simulate real-world training and generalization. However, using such VR instructional design should be cautioned as it can be extremely expensive to recreate 100% matched simulations to real-world events, may not be practical in some circumstances, and are not always required in order to reach the educational learning and training goals sought after.

DECIDING WHEN VR INSTRUCTIONAL DESIGN WOULD BE BENEFICIAL

Despite how luring VR environments might appear if they were to be used in an educational instructional design, educators should caution themselves as VR environments may be advantageous for some learning/training objectives, but may equally have pedagogical limitations. Thus, it is essential to understand both the benefits and challenges associated with using VR environments pedagogically, in order to understand the ceiling and floor effects of VR environments within the pedagogical context of instructional design **(Fig. 1)**.

Despite the number of levels created within an immersive VR environment, the instructional designer must be cognizant of the practical limits in overwhelming the user with too many immersive aspects (*i.e.,* ceiling effect), and ensuring to provide just enough immersive aspects (*i.e.,* floor effect) to optimize the user's attention and learning. Moreover, it is important to highlight that the immersive VR environment helps to reduce cognitive load and if too many pedagogical approaches are given at once, it may be counterproductive.

Figure 1. Instructional design concept map for understanding the ceiling and floor effects of an immersive VR environment
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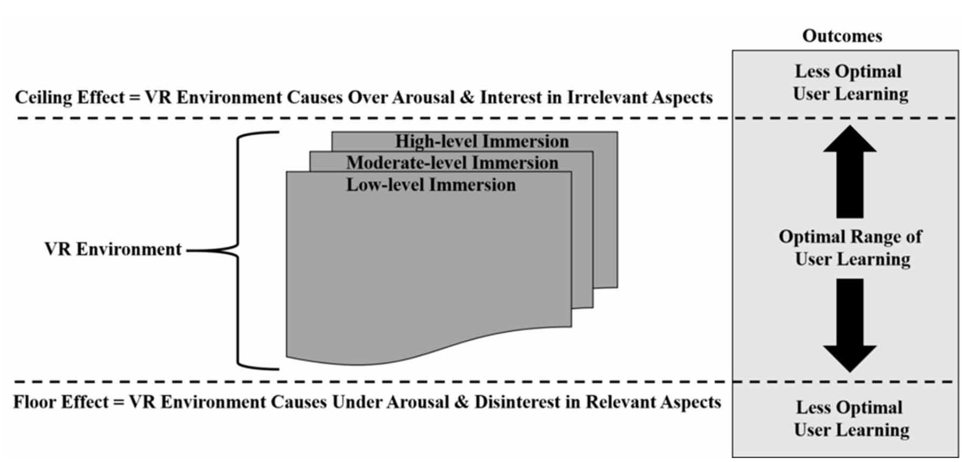

By following this instructional design concept map, the outcome would be an immersive VR environment optimized for the user's education. This outcome could then maximize the user's learning benefits by reducing unnecessary distractions (Harrington et al., 2018), and overcome the user's learning obstacles by making the content just surpass the most minimal arousal levels. Further, this concept map would help overcome the inherent issues with VR environments where an instructional designer's vision must meet a user's adaptation to and ongoing engagement within the VR environment to develop an ideal pedagogical application for training/educational programs. Notably, these user benefits and challenges may differentially influence the instructional design and training objectives of VR environments. Górski et al. (2017) suggested that there were three distinct, yet different, levels within the educational medical VR environment applications: 1) general (*i.e.,* conceptual skills), 2) procedural (*i.e.,* behavioral/ adaptive skills), and applied knowledge (*i.e.,* practical/ generalization skills). **Figure 2** illustrates the conceptualized differences between the user's knowledge levels directly related to the instructional design variations are required to reduce any potential academic achievement gaps when constructing an effective VR environment for pedagogical applications (Górski et al., 2017).

BENEFITS OF IMMERSIVE VR ENVIRONMENTS: ACCESSIBILITY, AUTONOMY & COST

Accessibility Within Immersive VR Environments

"Accessibility refers to the user's ability to find what is needed, when it is needed. Improved access to educational materials is crucial, as learning is often an unplanned experience." (Ruiz, Mintzer & Leipzig, 2006, p. 208). Consistent with this quote, VR environments can allow users anywhere in the world to access the same training so long as they have access to the required technological devices to permit them to become immersed within the experience (Kamińska et al., 2019). Accessibility of an effective education is perhaps best captured by the following quote: "Learning is a deeply personal experience: we learn because we want to learn." (Ruiz, Mintzer & Leipzig, 2006, p. 208). However, knowing the needs of the prepared and/or underprepared user is a critical factor in which their autonomy within an immersive VR environment may help to facilitate their learning and produce better educational outcomes, irrespective of the academic achievement gap.

Figure 2. Illustrates the conceptualized instructional design for the developing VR environments for ensuring optimal educational outcomes for the user based on the models proposed by Górski et al. (2017)
(A) *displays the venn diagram of the Górski et al. (2017) model when the VR user's experience is balanced in learning content across conceptual, behavioral/adaptive, and practical/generalization skills* **(B)**. *Further, instructional designers should be aware to permit flexibility for the user to adapt within such VR educational environments whereby at time they may need more conceptual than practical skills* **(C)***, more practical than conceptual skills* **(D)***, more behavioral than conceptual skills* **(E)***, and more behavioral than practical skills* **(F)**. *Permitting such flexibility may create more immersive VR environments with greater educational gains for the user.*
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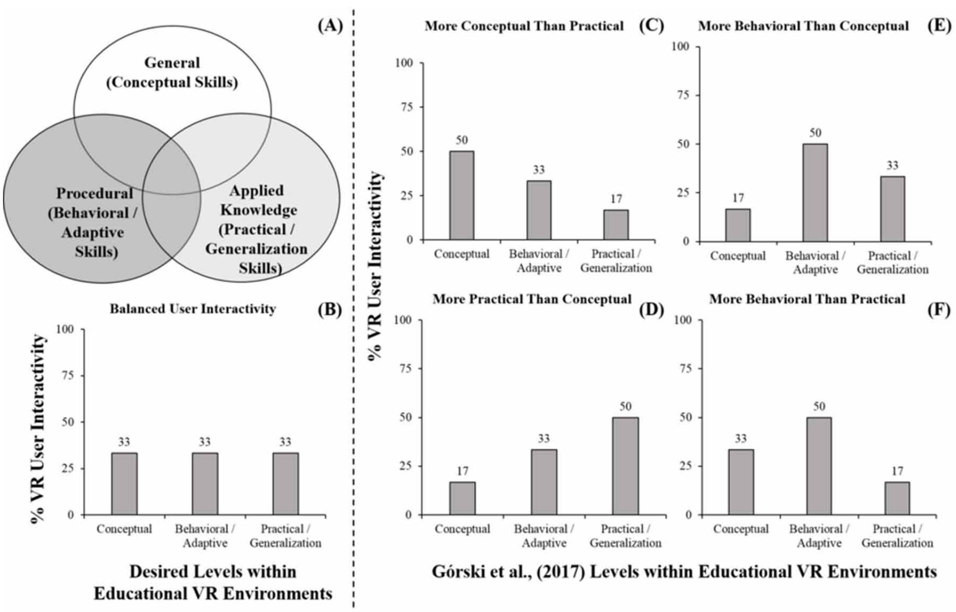


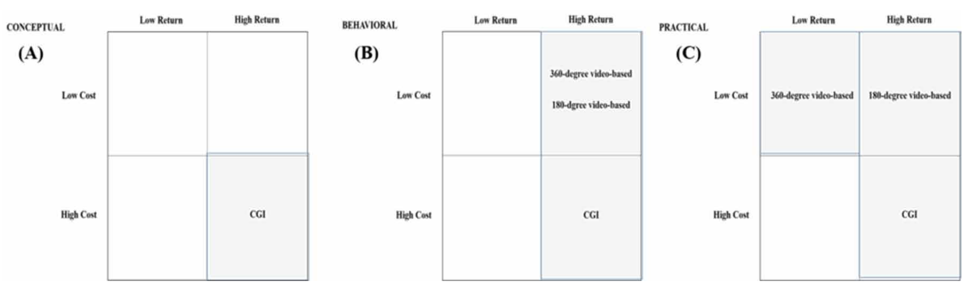
Autonomy Within Immersive VR Environments

Beyond accessibility, VR environments differ in the degree of autonomy that individual users might experience when accessing the identical VR environments repeatedly over time. Some VR environments can be accessed and experienced by the user, while others require an instructor to set them up or run the experience for a single or group of prospective users (*i.e.,* shared VR experience), and lastly, some are designed to require other users to interact with the main user (*i.e.,* cooperative VR experience) within the VR environment to complete a single experience (Kamińska et al., 2019). Therefore, the degree of the user autonomy is directly influenced by the desired educational goals of the training and the instructional design of the VR environment, in turn, defining the user's VR overall experience. However, identifying how much user autonomy is needed for the instructional design is a critical factor in determining the cost of developing immersive VR environments for pedagogical purposes.

Cost of Developing Immersive VR Environments

Monetary savings can be achieved over time when comparing the use of VR with 3D, 2D, and real models, as well as, tissues or patients (Górski et al., 2017). However, in the initial development stages of any technological tool, device, or software costs can be exorbitant. Because of these financial challenges in developing VR environments, a balance must be achieved between leveraging the expenses that go into developing the VR instructional curriculum and design, while maximizing the pedagogical/educational outcomes and detailing such cost comparisons for future research and development of VR experiences (**Fig. 3**). Such information can help future educational instructional designers of high-quality high-return investments compared to low-quality low-return investments when developing new VR environments for applied pedagogical instruction. Further, knowing such information may be essential in motivating and capturing the interest of users to seek engagement in VR environments within an educational context.

Figure 3. Probability squares of assessing cost and returns for developing effective applied learning technologies in VR Environments for conceptual **(A)***, behavioral* **(B)***, and practical* **(C)** *instructional design*



The ideal situation is to maximize high returns from the lowest cost across each of these three factors, but often times that may be less than ideal.Novel VR enviornments might require high cost to initially develop high returns and over time can be economically reassessed.

It is also imperative to understand how such a pedagogical immersive VR environment can transcend a wide-range of conceptual parameters to increase the user/learner's ability to fully comprehend what is being presented to them (**Fig. 4**).

Figure 4. Illustrates a conceptual framework for designing the most optimal immersive VR environment across a number of factors (i.e., conceptual – CGI, practical – CGI, practical 180-degree vide-based, and behavioral 360-degree video based) as they would relate to low and high returns (i.e., the financial investments that go into creating the technological and the pedagogical gains achieved by the user/learner).
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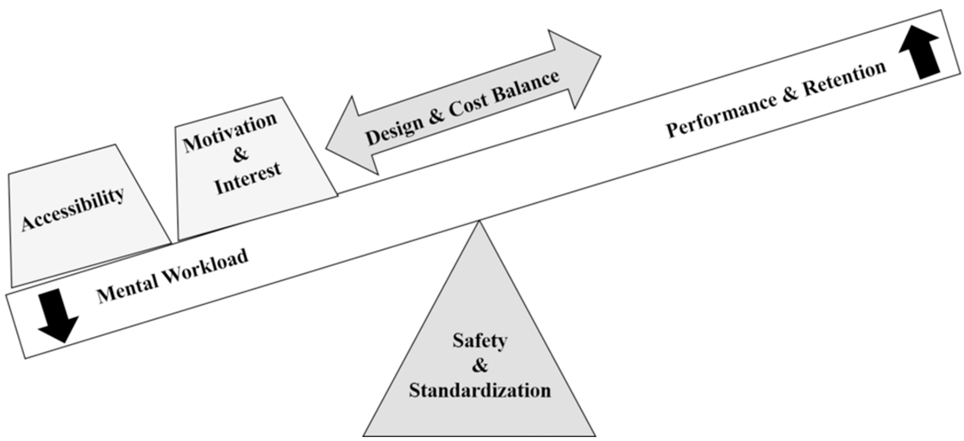


Obtaining and Sustaining User Motivation and Interest Within Immersive VR Environments

The use of exploring VR environments in grade school curriculums (*i.e.,* "VR field trips" in middle school students' social studies) has been shown to increase educational motivation and interest (Kamińska et al., 2019). Further, studies focusing on the use of VR technology in different learning contexts supports the findings that learners are more engaged and self-report that they understand the content being taught better. These benefits may come from the lower "task-unrelated images or thoughts" (Harrington et al., 2018, p. 993) (*i.e.,* improved attention) that are brought out through the immersive characteristic of these VR experiences. These findings are further supported by data showing that blinding students to the actual VR environments that they will be immersed into actually increases their focus upon entering the VR-environment. Harrington (2018) showed a significantly higher student level of engagement (*i.e.,* 360 video-based instructional content) and the student's preferred it when compared to a 2D video of the same content. This might be a key factor that warrants further investigation in developing VR immersive environments that encapsulate meaningful engagement for the learner through depth perceptual processing and/or visual feedback, which is critical for transferable pedagogical outcomes in VR environments. Ultimately, this type of learning could positively influence student's preference for a VR curricular format over others that in turn, promotes an increase in student motivation and educational interest.

Ekstrand (2018) stated that VR prevented *"neurophobia"* (*i.e.,* a fear of learning neuroanatomy), which provided insight in expanding the pedagogical approach from just viewing content to include exposure and re-exposure of the same content to increase user acceptability of the information being presented/taught. Using Computer-Generated Imagery (CGI) to reconstruct the neuroanatomy among 175 students, of which, 94% were willing to have VR integrated in their educational curricula because it helped them to improve their understanding of the course content. Thus, students directly report that having a better understanding of educational content can be achieved through VR, and then having the luxury of going over it multiple times, can facilitate a self-regulated means of adapting to and desensitizing students to their own inherent fear(s) of learning neuroanatomy. This latter point is compelling as it provides invaluable insight into the utility of VR when the user can determine how frequent they would like to experience the course content. This could further provide the instructional designers to anticipate the learners with the ability to augment and adapt within the VR environments to increase their motivational and educational interests in response to uninteresting, aversive, or noxious educational content. Such insightfulness can help the instructional designers to create supportive VR environments that may best address their academic achievement gaps with course content that intimidates them such as neuroanatomy and other forms of biological dissection of tissues (*i.e.,* both human and non-human).

Further, *"neurophobia"* has been an emerging issue that can also deter students from entering the biological and medical science fields and may reduce future medical professionals in the science, technology, engineering, and mathematics (STEM) fields if left unaddressed (*For Review See* Neuwirth, Dacius, & Mukherji, 2018); yet, VR might be able to leverage this very issue in a responsible and ethical manner through creative instructional design of VR environments that combine exposure/re-exposure immersion levels that desensitize the user to content that they might find aversive. By providing the user with the control to regulate how much they would like to tolerate in becoming immersed in such VR content, this may actually decrease their mental workload and increase learning. Further, if the user can control the VR environment this may increase engagement from students who would otherwise view the material as aversive and mostly result in course attrition, to follow through with the curriculum and perhaps continue to learn more content beyond the VR module.

Reduced Mental Workload Through Immersive VR Environments

Notably, VR can increase the user's motivation and interest, which makes it an attractive technology for integrating educational content with an immersive experience that is uniquely memorable. However, as with any attentional task, one's attention span and cognitive load can either be limited or limit how much information one attends to at a given moment in time (Feldon, 2007; Barrouillet, Bernardin, Portrat, Vergauwe & Camos, 2007; Oviatt, 2006). Unlike standard visual and attentional processing where humans are easily distracted by events, actions, objects, and movements within their visual field, VR headsets block out these competing peripheral and background distractors and increase the user to focus their attention on the foreground of the VR environment. The attention to the VR environment is also enhanced due to its novelty (Roussou, 2000). Thus, it can be argued that through these inherent features of VR, it may reduce the user's attentional load and free up more cognitive capacity stores for increasing skill acquisition and learning retention (Andersen, Mikkelsen, Konge, Cayé-Thomasen & Sørensen, 2016) to be freely available to become increasingly or fully immersed within the VR experience; thereby, facilitating the user's learning, memory, and post-educational outcomes.

Moreover, since VR also facilitates the first-person POV, this particular feature has also been suggested to further reduce the user's cognitive load to increase their learning capacity just by using the first-person POV. The first-person POV has been shown to improve the learning of new gestures. Mirror neurons are usually activated when the learner sees someone else performing a procedure. If this procedure is viewed from a first-person perspective, cognitive load is less important, and trainees are more able to replicate the procedure. (Fiorella, Van Gog, Hoogerheide & Mayer, 2017).

This latter point is critical as mirror neurons are the neurobiological/neuropsychological basis for empathy (Iacoboni, 2009), vicarious reinforcement, (Bandura, Ross & Ross, 1963), and more relevant to this VR context and enriched sense of learning that is validated by the user's brain responsivity to VR and their brain's ability to perceive the POV as being the user's own first-person experience. Thus, the first-person POV constitutes a powerful way in which 3D 180-degree stereoscopic VR experiences directly influencing the user's brain in ways that can optimize learning through VR environments that provide sound evidence that it can offer unique pedagogical benefits to the learner/user by improving their skill acquisition and memory retention.

Improved Learning Skill/Performance Acquisition and Memory Retention Through Immersive VR Environments

Several studies have begun to address the issues of learning performance and retention when using VR environments. In order to address this issue, the pedagogical designer's instructional plan must be comprised of a step-by-step approach that directly scaffolds the short-term learning objectives with the desired long-term learning outcomes of the curriculum. However, despite even the most well-defined and structured curriculum in VR, some difficulties might arise from the wide variety of and different intentions for how the VR environment was implemented within a given curriculum. Together, this begets the questions, which VR studies are consistent, reliable, and comparable in best addressing the issue of standardizing key factors for using VR in best pedagogical practices for educating the next generation learners. It may very well depend on the type of VR that is studied (*e.g.,* CGI, 360-degree video, 180-degree video, etc.), since the pedagogical objectives (*i.e.,* theoretical, procedural, practical knowledge, etc.) and what they are compared against (*e.g.,* books, videos, lecture, physical simulator, etc.) may be more important in capturing the user/learner's attention and sustaining their cognitive loads, while diminishing distractors to improve learning outcomes. Further, it has been shown that non-immersive VR can lead to improved educational performance (*i.e.,* less errors and reduced time to complete the task) in reproducing complex tasks, when compared to technical manuals and multi-media films. For simple tasks, there were no differences observed between non-immersive VR and multi-media films regarding the number of errors, but non-immersive VR did speed-up the time to complete tasks (Chao et al., 2017).

Another study by Smith (2018) aimed to compare computerized-images displayed between immersive VR, flat-screen VR, and written notes after having watched a video. They assessed the performance on a mannequin and measured their time to completion. The results showed that they failed to observe any short-term or mid-term (*i.e.,* 6 months follow up) differences between the groups, when compared to immersive VR. Surprisingly at mid-term, the non-immersive solutions produced significantly faster time to task completion when compared to baseline, but again without any significant difference between groups. Sheik-Ali (2019) mentioned that the speed to meet criteria is an important variable, but more importantly, in a surgical training context, the speed of surgical skill acquisition is arguably more important in order to become proficient enough to complete a later surgical task. They concluded that many studies have consistently shown a positive linear relationship between the use of VR/AR in surgical training and surgical skill acquisition, despite the tools used being rather different. To be clear, there is only one immersive VR tool, which uses hand-tracking instead of remotes. Regarding the influence of immersive

VR with CGI to complete a task, Smith et al. (2018) found no difference between the group using immersive VR and the group receiving conventional training. The authors further showed the same post-interventional outcomes with gradual improvements and lower retention scores at 6-months follow up. Thus, they stated that VR was at least as good as conventional training but did not surpass it. In a recent study, Andersen et al. (2018) showed that using VR with CGI for practical knowledge before a training course increased the benefits of the course and allowed the students to achieve better learning outcomes. They also showed that the more people were trained repeatedly in VR, the better their results were when compared to a single training of VR. This suggested that VR has additional educational gains influencing skills acquisition and memory retention through repeated exposures.

Regarding the theoretical knowledge and skill acquisition in healthcare, user-cases are similar to industrials cases: the possibility to enter a 3D reconstruction of a *"machine"* provides a better conceptual understanding. The possibility offered by VR to uniquely explore the educational content through an *"anatomy journey"* (*i.e.,* through VR moving through a biological organ to view new perspectives and connections within and across systems). Using a 3D CGI reconstruction of an organ, which is literally put in front of the learner to let the user artificially enter through and rotate this organ with intent that the user will become more familiar with the course content regarding knowledge of the organ. This way the user can explore the organ under every angle and have a better understanding of the different tissue layers and the relations between organs. Further, this experience offers the learner the ability to adopt a new perspective, that could not otherwise be achieved, without the VR environment. This finding is not only fascinating, but offers an endless range of new pedagogical possibilities. Therefore, VR is not only an entertaining way to learn new skills through technology, but it actually improves the learners *"visual field"* (*i.e.,* a VR-induced Proprioception) thereby expanding their understanding and approach to finding additional solutions to conventional learning problems. The exposure to these unique perceptual angles and vantage points is perhaps the largest advantage of using immersive VR environments over other forms of technology and conventional educational learning. Since these VR environments are based upon CGI that is directed by the theoretical knowledge underlying the course content, which are then aimed at increasing skill acquisition and retention of the content to be learned by the user. Concerning neuroanatomy, Ekstrand et al. (2018) found no difference in effectiveness between VR and textbooks as learning tools. However, they showed that VR prevented *"neurophobia"* among 175 students, and the authors stated that the results were encouraging. This may be perhaps due to the user being able to alter the imagery in the VR environment when compared to the fixed imagery presented by the textbook.

In cardiac anatomy, Maresky et al. (2018) found improvements in the user's results after learning through immersive VR environments. Thus, VR helps students to gain a better understanding of the organ itself, its structure-function relationships, its spatial connections, and its interfaces within systems biology, that can create a greater comprehensive understanding of the material within minutes in an immersive VR environment that would otherwise require reading hundreds of pages and weeks to months to achieve such understanding through conventional means. Another important feature is that VR environments in the biomedical fields help to overcome a real educational resource issue. Most dissections and surgical techniques are done in a time restricted and sample/organ tissue availability-dependent course (*i.e.,* the dissection or surgical laboratory). These laboratory courses require many students to shadow the instruction with little to no hands-on experience and often times result in less than optimal time viewing the actual procedure or details of the procedure that reduce the skills acquisition and applied learning of these concepts. Through VR environments, these learning gaps can be reconciled, improved, and even enhanced to prevent such learning gaps from occurring. These finding beg the question, how can immersive VR environment improve the user's learning retention? It is hypothesized that because immersive VR environments probably facilitate the user to understand better theoretical questions by being able to manipulate the structures/organs and understand how it works in a constructivist approach, or to acquire practical knowledge by being able to literally *"live in an educational experience"* and its different steps. Becoming fully aware, the user/learner has all what they need to gain a better understanding of the course content, which may then foster better skills acquisition and memory retention for generalization of applied learning. Altogether, the immersive VR environment may optimize the benefits of a lesson beyond convention pedagogical approaches, but would require standardization in order to accomplish this task.

Standardization of Immersive VR Environments

Similar to e-learning Ruiz et al. (2006) showed that the use of immersive VR environments standardizes the educational content and provides the same information and learning experience to all students, when compared to conventional learning. Further, the experience that is created in the immersive VR environment by the instructional designer and experienced by the user are equivalent to the teacher designing the curriculum and the student learning from the conventional educational experience. However, when an immersive VR environment is used for pedagogical purposes, this standardization may begin to exceed the expectations and expand the potential limits for the user/leaner; albeit, still within a standardized curriculum/environment.

Safety of Immersive VR Environments

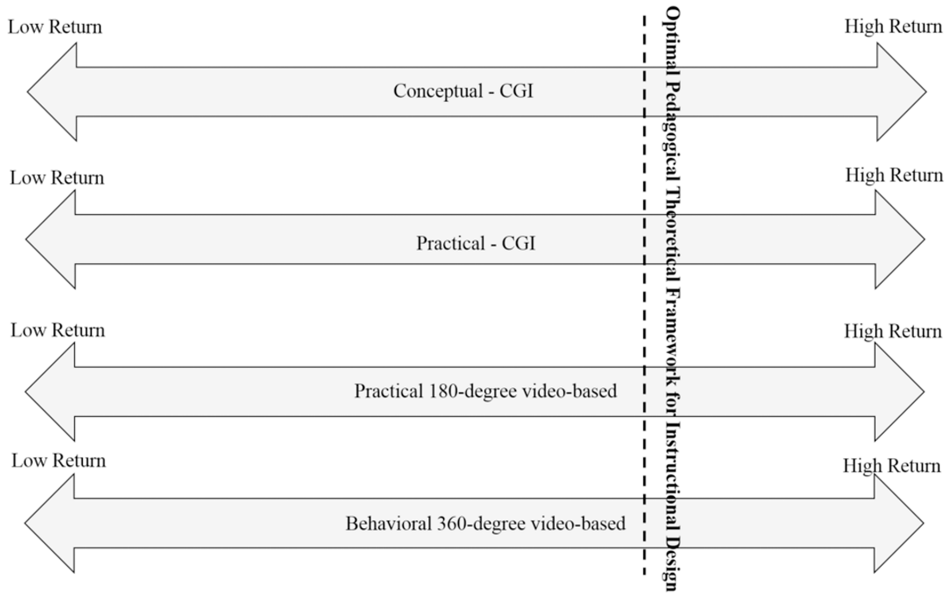
The immersive VR environment often allows the user to acquire the necessary training to do things that would otherwise be too dangerous (*i.e.,* an animal dissection, dissecting a brain, or human organ, calculating a drug dosage to give a patient, etc.) for most people to experience as a first time exposure within a real life situation (Concannon et al., 2019). Thus, such use of immersive VR environments can improve both the safety of the user/trainee/student as well as the individuals they might have to help post-training in real situations that are dangerous. Using a similar logic with respect to surgical education, the use of immersive VR environments can allow the user to acquire technical skills in a simulated environment without the possibility of harming patients (Concannon et al., 2019). This enhances the ethical component of the pedagogical approaches through immersive VR environments and further can increase the user/trainee's skills, confidence and decrease surgical risks that might otherwise occur in patients. Alternatively, immersive VR environments can be used for a situation that one specialist must know, and further through repetitious learning/exposure/re-exposure, it can help the younger students/professionals to be ready faster, which was one of the first immersive VR tutorials created by Revinax® (Ros et al., 2017). Moreover, immersive VR environments can help the user to face/experience situations that are rare, while increasing the user's readiness for real-life situations based upon their VR training. For example, Vankipuram (2014) developed an immersive VR simulator for resuscitation illustrating the utility of VR in this very generalizable translation of knowledge across VR to real-world contexts/environments. **Figure 5** below summarizes the overall instructional design goals for creative optimal immersive VR environments, in which the Revinax © model endorses and applies to their pedagogical framework for creating educational VR experiences with content that is learned faster, remembered more, and promotes skill acquisition and generalization from VR to real-world applications.

The goal is to balance the user's accessibility, cost, motivation and interest, amongst safety and standardization. The adaptive ability of the immersive VR environment should address decreasing the user's mental workload and increasing their performance and retention as a validity and reliability measure for successful pedagogical applications.

CONSIDERING SELF-REPORTED ADVERSE EFFECTS OF VR

Nausea and dizziness (*i.e.,* called VR sickness, motion sickness, simulator sickness and/or cyber sickness) can also occur for a temporary time-period when participants are immersed in the VR environment (Concannon et al., 2019; Kamińska et al.,

Figure 5. illustrates the conceptual model for developing an optimal immersive VR environment



2019). This occurs when participant's movement within the VR environment does not match their movement in the physical world (*i.e.,* a perceptual kinesthetic mismatch). Besides people who suffer from internal ear dysfunction, several factors can potentially contribute to experiencing sensations in VR that may result in this feeling. Consequently, the hardware used (*i.e.,* VR headset), the resolution quality of the VR displayed, and the refresh rate of the video frames captures, are among the main contributing factors for VR sickness. Alternatively, the quality of the content: frames per second, resolution, and movements can also contribute to VR sickness. Notably, VR sickness happens infrequently, but can occur in people who do not suffer from motion sickness, but is brought on by the novelty of the first time they are exposed to VR combined with feelings of nervousness due to the uncertainty of this new experience.

REVINAX® STEREOSCOPIC 180-DEGREE ENVIRONMENT

A Peculiar Instructional Design

The immersive VR environment that is typically created is often based upon either CGI or 360-degree video-based experiences. Additionally, CGI helps to recreate an environment and make an artificial environment seem more realistic to the user, whereas in contrast, 360-degree video-based experiences simply display real footage. Thus, CGI is interesting as it offers a unique platform in which to represent things that cannot be recorded and played back. Since CGI attracts much interest due to its full user interaction within the immersive VR environment, as a by-product, its pedagogical value becomes increasingly important. However, the main problem in developing immersive VR environments with such pedagogical value is that the cost to create this content is rather expensive (*i.e.,* additional design features and the more realistic the desired experience the more it will be expensive). Moreover, the time to create and deploy this high-value pedagogical immersive VR environment will still require hardware for it to be used in a dedicated/restricted area (*i.e.,* which are not totally standalone). The 360-degree video-based experiences can supplement the immersive VR environment by helping people to project/insert themselves within the VR content, context, and/or situation that is pedagogically designed by the instructor.

The user interaction comes from the unique experience (*i.e.,* perceived simulation of a first-person POV) and what is then captured by embedded questions or decision trees testing the users/learners comprehension of the task within the immersive VR environment as it appears on the movie through these 360-degree video-based displays. These videos are faster to produce than CGI, the content is intrinsically realistic (*i.e.,* as they are pre-recorded from real-life events) and it is therefore easier to deploy even outside of the traditional VR HMD. However, the problem arises in 360-degree video-based displays when the user is trying to learn how to complete a procedure (*i.e.,* practical knowledge), since they are not fully capable of positioning themselves within the first-person POV to activate their mirror neuron systems to fully immersive themselves within the VR pedagogical content as intended. Revinax® produced in 2014 a stereoscopic 180-degree 3D video-based recording of an actual surgical procedure in real-time and since 2015 has been dedicated to advancing and further developing this technology as a pedagogical tool based on user feedback. Revinax® accomplishes this by creating a tutorial that involves three steps: 1) the surgical procedure is recorded in 3D video-based format from the surgeon's point of view (*i.e.,* using the equipment worn by the surgeon performing the procedure in real-time); 2) the 3D movie is then organized into chapters corresponding to the different steps of the surgery (i.e., with calibration and synchronization of the two videos); and 3) clinical imaging and data are then incorporated into the tutorial to make it a pedagogical immersive VR environment.

Among the content created, the surgical video covering the medical procedures for carrying out an external ventricular drainage, was instrumental in allowing trainees/students to view the procedure from a first-person POV perspective with the following educational intervention-based goals: 1) enhancing their memorization, 2) increasing their understanding of and confidence in implementing the procedure, 3) minimizing error when conducting the procedure, and 4) ultimately the training/educational intervention would decrease both surgery risks and time in surgery. Trainees/students could also access other patient data that underwent the same procedure to help them draw comparative assessments, weigh out any other alternative risks and/or concerns that they might have in replicating the procedure, and increasing their reliability of the procedure to better understand the case study with deeper analytical, critical, and clinical thinking. Further, theses resources were supplemented in the immersive VR environment with the patient's Computerized Tomography (CT) scan and an educational 3D model of the organ in which the surgery would occur. Taken together, this immersive VR environment in theory provides in a *"hands-free"* manner, virtual surgical, clinical, and educational resources that could be potentially be used in real-time within an operating room prior and during surgical interventions. However, it is also important to note that while in the operating room, the trainee/student/surgeon user could pause or replay the immersive VR 180-degree stereoscopic video-based intervention and view patient data, without actually making decisions to guide the surgery or actively influence their environment. The unique experience that Revinax® designed was, in this particular context to allow an immersive view of the surgery while allowing access to other patient information. The first-person POV allows the user to see themselves as if they were the actual surgeon performing the operation(s). In other experiences, Revinax® recorded simultaneously the first-person POV of different members of the surgical team. The ability to switch to other views allows the learner to envision what other members of the surgical team are doing at specific points within the surgery.

As described in Ros et al. (2017), when surveyed, a large majority of participants viewing the immersive VR environment tutorial saw the benefit of using it as a part of the teaching program and felt that it had a beneficial effect on their learning outcomes. One of the interesting results obtained from this study was that there were no age differences observed (*i.e.,* cohort was composed of a wide range of healthcare professionals from young students to old practitioners). Indeed, as this is a video-based environment, people may be familiar with the context. This helps to bridge and reduce/attempt to eliminate the technical gap, which can be perceived across real/VR environment and the academic achievement gap observed by students based on their learning styles (Neuwirth, Ebrahimi, Mukherji & Park, 2018; 2019) and how redefining student diversity may further influence these outcomes across generations (Mukherji, Neuwirth & Limonic, 2017). Other studies have been launched, including more than 450 participants attempting to address these very issues at the core of modern learning and immersive VR environment integration as a powerful pedagogical tool. The first set of results have helped increase how to understand the place and/or setting in which using immersive VR environment would be most optimal for the learner within this environment. One way this was achieved was to assess the retrieval, reconsolidation, and retention of knowledge by comparing a group that read a technical note versus another group that had been exposed to the same technical note plus access to the immersive VR environment. Students who were trained with the immersive VR environment showed significantly better immediate memorization than students trained without the immersive VR environment. The same trend was observed (*i.e.,* without reaching significance) in the groups six months post-training. Another study aimed to assess hands-on training within immersive VR environment compared to another group who had a traditional lecture. The results showed that the immersive VR environment helped to speed up the time to complete the procedure. Interestingly, both groups had the same results while checking the items corresponding to the different steps of the procedure. This controlled for the key differences the users experience through the immersive VR environment. The outcomes showed that the lecture group performed better in answering theory-based questions prior to completing the procedure. One of the values of developing immersive VR environment tutorials are: the tutorial is affordable, easy to comprehend, and facilitates efficient learning; these benefits can help address the problems reported by the World Health Organization (WHO) (2015) concerning surgical training globally. Indeed, not everyone can afford to have access to a laboratory or an operating room with the highest caliber of technology, but a simulation training center may help to leverage the financial and practical problems surgeons face globally by expanding telemedicine through such applied VR pedagogical applications.

Challenges of Immersive VR Environments and How the Revinax® Model Addresses Them

Some VR hardware requires the trainer or educator to have specialized knowledge (Concannon et al., 2019), which can be a barrier to deploying the *"full"* VR experience. Some VR environments lack visual realism due to the limits of producing accurate graphics, while inaccurate or unrealistic details can further deviate away from the intended immersive VR experience; thereby, detracting the user from the believability of the immersive VR experience (Kamińska et al., 2019). As such, creating a more realistic environment can increase the cost of producing the VR experience or lead to other restrictions such as limiting the interactivity of the VR experience (Kamińska et al., 2019). One of the reasons that Revinax® chose to use the 180-degree video-based immersive VR environment first-person POV experience was that trainers did not require much specialized knowledge to use the technology. Further, it also allows the user to create content that is intrinsically realistic and more familiar to the user. Thus, the users can adapt to the content easily, which may help to integrate it in a wide-range of educational training programs. Further, video-based immersive VR environments helps to decrease the price to create content, and is able to represent a wide range of situations as pedagogical context for instructional use. Although, there are various ways to create video, the first-person POV has been proven to be an important pedagogical tool with more efficiency over other video content. Finally, Revinax® has committed to make content available through easy deployment and provide users the choice of a cross-platform approach in order to deliver the content in a VR standalone headset along with smartphones.

INCORPORATING VR INTO A TRAINING PROGRAM

Changing an already existing training program or creating a new training program should always begin with a user needs assessment. During this assessment phase, multiple options for training delivery should be assessed and the decision to use immersive VR environments as part of the training program along with the justification should be documented. Although Concannon, Esmail & Roduta Roberts (2019) found a positive outcome for immersive VR environments in 35 out of 38 experiments they reviewed (*i.e.,* 92% efficacy rate), caution should be exercised as immersive VR environments is not the solution for every training problem nor should it be used just because it is an attractive technology. Regarding the theoretical knowledge, immersive VR environments can be used as mentioned for a conceptual/structural understanding. Likewise, the procedural and practical knowledge for immersive VR environments should be considered when the training problem that needs to be addressed is related to experiential training. Experiential Training corresponds to the fact the learner needs to live the situation, to understand, gain experiences and thus will be able to become proficient. How to define when experiential training is indicated? When it is only the fact to have lived the experiences, which allows the trainee to have a full understanding. When you wonder how to show people and you are thinking the best way would be to take everyone in that context to make them live the experience, experiential training is indicated. Although technology and learning pedagogies have developed considerably over the last 15 years, the approach that Ruiz, Mintzer & Leipzig (2006) provided helps the field to better understand the pedagogical value of incorporating different learning methods into immersive VR environments. "Traditional instructor-centered teaching is yielding to a learner- centered model that puts learners in control of their own learning" (Ruiz et al., 2006, p. 207). Specifically, experiential learning and social constructivist learning theory accompanies the incorporation of immersive VR environments into any training program (Concannon et al., 2019). Adults learn better, when they are able to determine what they need to learn, explore the topics themselves, and then apply their knowledge actively. The autonomous and experiential nature of virtual reality makes it a good-fit with adult learning theory. Consistent with this approach, this is why Revinax® wanted to create a learner-centered experience in which the user feels being directly immersed within the middle of any immersive VR learning environment to have access to everything he or she needs surrounding them to enhance their learning.

Once it is determined that virtual reality should be used, it is important to define which kind of *"VR"* would be the best pedagogical and instructional method to answer the users' training objectives: Through CGI – when the context cannot be represented for practical or for conceptual knowledge / 360-degree based-video display to understand a given context, can be considered procedural. In contrast, the 180-degree first-person POV for teaching practical or procedural content with the goal to be deployed at large scale. Of course, the cost of the content creation, its volume, the hardware used to deploy it, and the number of people who have to undergo the experience can increase the variability of the outcomes and the potential applied cross-applications of any given pedagogical VR intervention.. However, Górski et al. (2017) identified a sound methodology for building Knowledge-Oriented Medical Virtual Reality (KOMVR), which is a six-step process: 1) identification, 2) justification, 3) knowledge acquisition, 4) knowledge formalization, 5) application and 6) implementation. From such a pedagogical needs assessment, the educator can define the user group and what they want the learner to accomplish during the training. As such, the theoretical framework for the KOMVR maps directly onto the training objectives to facilitate a deeper level of knowledge and from there to produce a range of acquired skills that may be useful for theoretical, practical, procedural, yet generalizable behaviors with the intent for applied purposes, within the immersive VR environment and potentially the real-world.

The second stage of KOMVR is justification, which includes planning who should be a part of the development team, estimating the work hours, calculating hardware and software costs, obtaining funding or developing a business plan and assessing the project risks (Górski et al., 2017). During the development process, the immersive VR environmental experiences should be tested by a diverse group of potential users/stakeholders to obtain feedback relating to functionality, effectiveness and the capability that addresses whether or not the experience adds to the training program (Kamińska et al., 2019). This can be done with a combination of survey questions targeting usability such as the System Usability Scale (Kamińska et al., 2019) and open questions to determine simple improvements that could enhance learning and the user experience. It is important to obtain feedback from a range of users as well as teachers and surgical experts in the field as the system and the experience will be viewed very differently by these groups.

CONCLUSION

The motivation and impetus to develop the immersive VR environment tutorial was brought on by the experiences users reported from the training program. Due to the practical limitations of shadowing surgeons within crowded operating rooms, the inherent set backs were the difficulty of medical professionals being allowed an appropriate/optimal view it of the surgical and nursing procedures that would increase their pedagogical applications of what they learned via direct observation of every procedure. The surgeon "mentoring" via shadowing within the operating room happens with the trainees /medical professional assisting the mentor. Since the trainee/medical professional is usually shadowing beside, behind, or even facing the surgeon the learning/pedagogical vantage point/perspective may be a self-limiting variable within the pedagogical approaches in acquiring skill acquisition of the surgical technique under study. Even when the user can see accurately what on the surgeon is doing via shadowing in real-time, they may not have the correct vantage point in order to acquire, consolidate, reconsolidate, and generalize the correct translational application of the surgical technique under study through natural observation means. Thus, the human brain has arguably some learning limitations through which it can optimally acquire information in which it may not fully/correctly memorize information in which it is presented. Further, the human brain can inadvertently make mistakes during the learning acquisition period, when the individual is tasked with attempting to (re)produce the surgical procedure from conceptual to practical generalizations. This is one explanation as to why it increases learning competency to acquire the skill acquisition procedures to reproduce these practical skills. Moreover, the observer through this shadowing/naturalistic observation methods may have learned something through the process, but due to the constraints of the human attention span and environmental distractors, how much is accurately learned in order to generalize and apply to practical application may be more limited than once thought. Thus, it poses the question, how can one address this inherent learning gap when trying to acquire new information during real-time surgical shadowing/observation (*i.e.,* which is what is conventionally considered the status quo)?

Additionally, through this comprehensive, yet conceptualize understanding of the limitations of shadowing and naturalistic observations, the present study proposes that it was not possible to provide/optimize these experiences to surgeons locally or abroad in other countries. A Lancet report (2015) for WHO stated that surgery should be considered as one of the top priority medical interventions for advancing global health. The catalyst for this is that five billion people globally do not have access to surgery. Further, to maintain this insufficient medical coverage, the surgical workforce (*i.e.,* not only surgeons, but inclusive of all medical health professionals participating in surgeries) needs to double by 2030 to address this very issue. Teaching people essential surgeries (across ~44 medical procedures) could save up to five millions lives per year. The theory behind this proposes the question, how then can we achieve that goal? The answer may lie at the interface of training people in remote areas with telemedicine through immersive VR environments from more advanced medical areas globally? From these immersive VR experiences, a global telemedicine workforce may be assembled to address these very issues. Further, to provide surgeons/surgical students and medical professionals with a portable/accessible tool, which can help them to have a better conceptual and translational understanding of a surgical procedure through immersive VR, may help to circumvent the pedagogical inherent issues in natural shadowing/observations through a more immersive VR environment as with the Revinax® model that addresses these issues to optimize the pedagogical outcomes of the surgeon/medical professional to increase future generations of biomedical educators in the field.

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