ASSESSING ADULT LEARNING THROUGH IMMERSIVE VIRTUAL REALITY TECHNOLOGY

By

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Dissertation Submitted

in Partial Fulfillment of Requirements for the Degree

Doctor of Education

College of Education

Frostburg State University

April 2023

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Acknowledgments

I would like to express my deep gratitude to my dissertation chair, Dr. Seniz Celimli-Aksoy, for her guidance, encouragement, and incredible support throughout my entire doctoral experience. Her expertise in quantitative methodology is only surpassed by her ability to teach a very stubborn doctoral student (basic) statistical analysis. I am also extraordinarily grateful for my committee members Dr. Kristine McGee and Dr. Rita Thomas for their guidance, collaboration, empowerment, and overall support throughout my research and dissertation process.

Without my scholarly colleagues, especially FSU's 2019 Ed.D. Cohort, this journey would be far less enjoyable, and at times, absolutely impossible. Specifically, Sharon, Colleen, and Keia, I am so grateful for your friendship and your ability to see some flicker of academic greatness in my work that, at times for me, was faded and blurred. Also, a special thank you to Dr. Sybil Gotsch—Mount Holyoke forever shall be.

To my family and friends, thank you for your love, support and complete understanding of my insane desire to never stop learning. Maclynn, I tried to make your world a better place; let me know how that worked out for you.

Finally, I dedicate this project to Stacey, my mom, and JillTheDog. There is no way this work was done solely on my own; you empowered me from the first day of class to the last typed word of this study and without your support and (at times tough) love, I cannot fathom the ability to complete this evolution in my education journey.

Abstract

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Virtual reality (VR) as an emerging technology has extreme potential to revolutionize online higher education for adult students through immersive and engaging learning experiences. Lower cost and advancing research in VR technology and immersive simulation software offers unique opportunities for adult students to engage in a virtual learning metaverse classroom as part of an online course curriculum. As technology tools, like VR, in education are reimagined for the classroom, curriculum design and delivery must also be reimagined to address the needs of a growing population of adult learning students studying in college programs. Understanding learning outcomes specific to adults using emerging technology is key to understanding how emerging technology can integrate into higher education curriculum delivery and design. Utilizing a constructivist theoretical framework and a quantitative research design, this study aims to evaluate the effectiveness of VR for adult student learning academic achievement.

Like most technology teaching tools, effective VR classroom experiences require deep consideration into the design and delivery of curriculum. This study utilized an andragogy framework to develop curriculum specifically for an adult student population. Concurrently, a whole-part-whole learning approach to deliver the study's biology curriculum studying the animal cell and describing the translation and transcription of

DNA to mRNA was instituted. This dissertation seeks to remedy gaps in research where curriculum is delivered through a VR experience but without proper curriculum designed specifically for the adult learner. Also, this study informs the research by presenting a well-designed and engaging adult student learning experience in a VR metaverse classroom using a live synchronous VR instructor.

Keywords: virtual reality, online learning, adult learners, immersive presence, metaverse

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Chapter 1 – Introduction

Innovative research and technology merging with teaching and learning throughout the past decade is a staple in delivering educational content at the collegiate level. Ninety-nine percent of all higher education institutions use a learning management system via the internet to synchronously or asynchronously provide higher education curricula (Johnson et al., 2015). Capitalizing on the benefits of technology to deliver curriculum to students has shifted how professors teach, and students learn new knowledge. The combination of students who cannot attend onsite classes and educational programming that cannot be delivered through traditional or current online pathways creates a gap in providing some college-level academic content to different populations of students (Johnson et al., 2015). The COVID-19 pandemic has enlarged learning gaps, mostly among students who were not permitted to attend in-person classes or when institutions improperly use technology to deliver the academic curriculum (Dorn et al., 2020).

Academic programs relying heavily on laboratory scientific hands-on educational curricula are not readily deliverable to students online (Dorn et al., 2020). Virtual reality technology, specifically immersive virtual reality technology, can deliver hands-on and program-specific academic content to students that most online and hybrid technology is currently ill-equipped or incapable of providing. Although the technology to provide a hands-on curriculum exists in VR, almost all VR education delivery methods are still considered a newly emerging technology in higher education and have not been widely accepted as a curriculum delivery tool (Hamilton et al., 2021; Jensen & Konradsen, 2018).

There is a gap in assessing student learning outcomes through IVR technological curriculum delivery and testing research, specifically for non-traditional (adult learning) students. Adult learners have unique learning needs and characteristics that differ from children's or those categorized as traditional students (Knowles, 1984; Merriam & Baumgartner, 2020). Knowles's (1984) view of adult learning provides the basis for his theory of andragogy as it suggests that adults are self-directed learners who are motivated to learn when they see the relevance of the content to their own lives. Adults have accumulated knowledge and experience that can be used as a resource for learning (Knowles, 1984; Merriam & Baumgartner, 2020; Taylor & Marienau, 2016). Adults learn best when the curriculum is problem-centered, collaborative, and designed around their learning styles and preferences. VR, specifically IVR, is uniquely positioned to establish a new technology model to instruct adult learners in programs usually relegated to an in-person classroom.

Statement of the Problem

VR is a computer-generated simulated environment where people can interact using hardware and software technology (Hamilton et al., 2021; Radianti et al., 2020). Sherman and Craig (2019) define VR as "immersion into an alternate reality or point of view" (p. 8). IVR, a type of VR, relates to a suspended sense of actual reality while physically interacting with an alternate reality in a 3-D immersive environment (Hamilton et al., 2021; Sherman & Craig, 2019).

Scientists have studied technology-aided education since the 1970s; however, VR software and hardware were relegated to private research facilities and the U.S. military due to the expense and inaccessibility of commercially produced hardware and software.

Therefore, VR software and hardware were not widely available outside these institutions until recently (Hamilton et al., 2021). Since 2013, however, VR hardware and software have become economically feasible for modern consumers since the release of several commercially designed head-mounted devices (HMDs), like Meta's Oculus series or HTC's Vive series (Hodgson et al., 2015).

Since the commercial release of VR equipment to the general consumer, academic research studying VR as a learning tool has increased. Nevertheless, very few IVR academic research studies have used an adult learning theoretical framework to develop a curriculum, utilize VR equipment to deliver the curriculum in an IVR alternate reality, and assess student learning outcomes (Hamilton et al., 2021; Jensen & Konradsen, 2018; Radianti et al., 2020). Of the few VR research studies released, traditional and non-traditional learners are mixed in the participant pool and the academic curriculum is rarely offered and evaluated for learning success in VR. There is a need to evaluate learning success for non-traditional students to establish if VR is a valuable technology tool to deliver the curriculum.

Since 2013, under 100 peer-reviewed empirical research studies have analyzed IVR technology learning delivery methods specifically for non-traditional adult students (Hamilton et al., 2021; Radianti et al., 2020). Of those studies, less than half were quantitative models examining VR as a curriculum delivery tool and assessing any student's (traditional or non-traditional adult learner) learning (Hamilton et al., 2021; Jensen & Konradsen, 2018; Radianti et al., 2020). Only a handful of VR studies contain any theoretical framework specifically assessing student learning outcomes (Radianti et al., 2020). Additionally, no research study has incorporated a live IVR instructor teaching in an IVR metaverse classroom concurrently with a student. Chapter 2 will further explore the gap in previous VR and online studies.

Purpose and Significance of the Study

This study aims to assess the learning outcomes of non-traditional students using an online IVR curriculum delivery method to understand concepts in an academic program usually taught in a traditional onsite lecture or laboratory setting. Previous research has guided this study in that it has elevated the need to study learning outcomes when IVR is used as a learning tool specific to non-traditional learners. Virtual Reality (VR), Augmented Reality (AR), and Immersive Reality (IVR) are emerging technologies whose implementation into educational delivery methodology has only surfaced since 2010, with research gaps where the participants are not solely non-traditional students. This study uses a curriculum designed and delivered using adult learning theory within an IVR metaverse classroom to assess the participants' learning outcomes. This study is unique because the research design includes an IVR metaverse classroom where a synchronous IVR instructor delivers a specific and intentionally designed and delivered curriculum to a particular cohort of only adult learning participants.

Research Questions

This study addresses the following research questions:

1. How effective is immersive VR technology compared to conventional classroom delivery methods for adult learning (non-traditional) students studying a hard-science curriculum?
2. What is the difference in test scores between adult students who study science in a VR and a non-VR learning environment?

Study Design and Methodology

This quantitative study assesses non-traditional students' learning outcomes through a hard-science curriculum using VR and 2D online learning methods. The constructivist learning theory informs this study with an andragogical lens framing the design and delivery of the curriculum within the methodology.

This study had four distinct but identical participant phases. The first phase included one survey to determine participants' non-traditional student status and collecting demographic data (Appendix A) When a participant was deemed eligible, a second survey was provided to gain information about participants' familiarity with online courses, VR software, and video games (Appendix B). The second phase saw the pre-test (Appendix C) administered to all participants, phase three included the delivery of an identical curriculum to each learning method classroom (2D online and IVR), and phase four administered the post-test (Appendix C) to all participants. Data was collected from the pre and post-test results and responses from both surveys. When appropriate, data were coded in preparation for statistical analysis, which included a repeated measures ANOVA model comparison analysis.

Theoretical Framework

Constructivism is a learning theory suggesting that individuals actively construct knowledge and meaning from their experiences and interactions with the world (Bruner, 1961; Piaget, 1954; Vygotsky, 1930–1934/1978). According to constructivism, learning is not simply acquiring new information but creating and refining one's mental models or cognitive structures. Learners are seen as active participants in the learning process, not passive recipients of knowledge. Consequently, learners bring their prior knowledge, beliefs, and experiences to the learning situation, which they use to make sense of new information and construct new understandings (Bruner, 1961; Piaget, 1954; Vygotsky, 1930–1934/1978).

In a constructivist framework, learners are seen as active participants in the learning process, not passive recipients of knowledge. Therefore, when learners bring their prior knowledge, beliefs, and experiences to the learning situation, they use them to make sense of new information and construct new understandings. Constructivism emphasizes the importance of learner-centered instruction, where teachers act as facilitators, rather than directors, of learning. Learners are encouraged to engage in inquiry-based activities, problem-solving, and peer collaboration to construct their knowledge (Dewey, 1916; Piaget, 1954; Vygotsky, 1930–1934/1978). Overall, constructivism is a learner-centered approach to education that emphasizes the active participation of learners in constructing their knowledge and meaning (Bruner, 1961; Dewey, 1916; Piaget, 1954; Vygotsky, 1930–1934/1978).

Limitations

Limitations of this study include the technical aspects of the curriculum delivery systems within VR. A third-party vendor developed the immersive VR metaverse to deliver the study's complex science curriculum. The study is limited to operating within the vendor's software and hardware parameters to establish the IVR metaverse. Furthermore, participants in this study must be physically non-disabled to manage the VR hardware, which includes the ability to hear, see, move around a room, and physically interact with the VR software and others inside the metaverse. Also, motion sickness is a potential hazard of VR use; operating within a VR metaverse provides a realistic impression that the body is moving when the participant's body, in actuality, is still.

A limitation of this study is in its scope; it only analyzes testing results and does not address any qualitative factors of participants testing anxiety or behaviors toward using an emerging technology, which may skew testing responses. As a purely quantitative study, data analysis is contained only to the dependent, independent, and some variable factors, which limits the analysis of the study by not considering other qualitative emotional factors.

Definition of Terms

The following terms are used throughout this study. Definitions are provided to clarify how each term is used throughout the document.

- *Adult learners*: A non-traditional student.
- *Andragogy*: A framework developed by Malcolm Knowles (1984) to train and teach adult learners.
- *Asynchronous learning*: Forms of education, instruction, and learning that do not occur in the same place or simultaneously (Great Schools Partnership, n.d.).
- *Augmented reality* (AR): Reality mixes virtual perceptions with actual perceived reality (Sherman & Craig, 2019).
- *Immersive VR* (IVR): A physically immersive virtual reality visual display that provides a sense of proception, causing the user to perceive items in a space where they feel physically present (Sherman & Craig, 2019).
- *In-person learning*: A form of instructional interaction that occurs "in person" and in real time between teachers, students, colleagues, and peers (Great Schools Partnership, n.d.).

- *Metaverse*: A virtual space online where VR avatars interact.
- *Non-traditional students*: Also known as adult learners, a population of students that identify with one of the following attributes: be at least 25 years old, attend school part-time, work full time, be a veteran, have children, wait at least one year after high school before entering college, have a GED instead of a high school diploma, being a first-generation student (FGS), are enrolled in non-degree programs, or have reentered a college program (MacDonald, 2018).
- *Online learning*: Learning that takes place over the internet (Great Schools Partnership, n.d.).
- *Pedagogy*: A method of teaching a practical application of education.
- *Presence*: The subjective experience of being in one place or environment, even when one is physically situated in another (Witmer & Singer, 1998).
- *Synchronous learning*: Forms of education, instruction, and learning that occur simultaneously but not in the same place (Great Schools Partnership, n.d.).
- *Traditional students*: A population of students that attend a higher institution of study toward a degree program immediately upon graduation from high school and who are approximately 18 years of age (MacDonald, 2018).
- *Virtual reality* (VR): The immersion into an alternate reality or point of view (Sherman & Craig, 2019).

Organization of the Study

This chapter covers the problem, reason, and significance of the study. Also, this chapter defines two research questions, introduces the study, key terms, one theoretical framework, and two distinct curriculum design and delivery models are provided.

Chapter 2 is an extensive literature review of the use of VR in education research and identifies the gap in learning assessment for non-traditional learners using new and emerging technology. Chapter 3 details the study's methodology, including the sample population, collection, data analysis, researcher's role within the study and ethical consideration. The results, analysis, and findings of the study are provided in Chapter 4. Chapter 5 provides a detailed discussion of the findings, describing the limitations and future research potential from the study's results.

Chapter 2 – Review of the Literature

Chapter 2 provides a detailed and comprehensive review of the literature regarding VR and its use in education and its use in assessing non-traditional student learning outcomes. Additionally, this chapter draws upon various sources to synthesize the existing body of knowledge and identify gaps in the current research. Through this review, this study aims to gain a deeper understanding and insight into IVR, VR, and AR and its applicability as a curriculum delivery tool in higher education.

First, a review of the evolution and history of online instruction in higher education is provided. Reviewing the evolution of online instruction allows the reader to level-set and understand current teaching and learning technology and how education and training have evolved to incorporate online curriculum delivery, outcomes, and assessment into higher education classrooms. Second, this chapter discusses VR's use in education, training, and learning, specifically addressing the evolution VR is currently undergoing, from training to a dedicated education curriculum delivery tool. Third, the elements of effective VR development in education is discussed. Fourth, this chapter reviews the theory of andragogy and its intersectionality with the whole-part-whole learning approach and its effectiveness on designing appropriate curriculum for the adult learner. The chapter ends with the effects of immersive VR as a learning outcome assessment tool and the constructivist theoretical framework molding this study.

History of Online Instruction in Higher Education

Before the 1990s, alternatively delivered instruction (considered non-traditional) included methods involving television, radio, and even parcel post (Kentnor, 2015). Initially seen as a niche way of teaching and learning, non-traditional distance education has evolved into a mainstream delivery system with ease and growing access to the internet. Starting in the 1990s, structured corporate training using online learning modules enabled large corporations to train their workforce, reduce costs for travel and training, and limit time away from the office (Roffe, 2004). Higher education academia embraced online distance education in the late 1990s, and by the late 2000s, online courses were widely available to millions of college students in various disciplines (Kentnor, 2015). Between 2007 and 2010, online enrollments in college-level academic courses increased by over 18%, and students taking at least one distance learning course increased by 16% from 2012 to 2016 (Seaman et al., 2018). Interestingly, over half of all online learning occurs relatively close to the student's home institution, as over 50% of students taking at least one online course also took an on-campus course (Seaman et al., 2018).

While online education is an increasing opportunity for students to fulfill academic requirements, not all educational programs have a robust online catalog of courses. According to Gallagher (2019), the most commonly enrolled program is in the business or marketing academic program field. The top five online programs include no hard-science curriculum and highlight the computer sciences, marketing, business, education, or other sociological areas of study (Gallagher, 2019). Still, online learning increases accessibility for those who cannot study during traditional class times and require asynchronous courses, even though some academic programs are not readily available in an online teaching format (Seaman et al., 2018).

While asynchronous learning and non-traditional class times are ripe for adult learners to succeed in online courses, national databases holding education statistics of enrolled students in online programs do not differentiate between non-traditional and traditional students. For example, the research of Seaman et al. (2018) addresses trends in distance learning without specifically separating non-traditional (adult learners) and traditional student participation in online courses. Seaman et al. (2018) provide data supporting the growing number of students (both traditional and non-traditional) taking online college courses and identifies a shift in online curriculum delivery; however, their research does not differentiate between non-traditional and traditional student populations.

Some studies specifically address differences between non-traditional (adult learning) and traditional students within higher education research; however, the definition of adult learner (non-traditional) can vary depending on the methodology used to collect the data (MacDonald, 2018). Currently, there is not a widely accepted definition for "adult learner" or "non-traditional student" within standardized educational research organizations like the National Center for Education Statistics (MacDonald, 2018).

Previously, non-traditional (adult) learners were labeled as such once the student turned 34 (MacDonald, 2018). Today, several other factors, including financial and family status and high school graduation rates through persistence and retention, contribute to a "non-traditional" student definition (MacDonald, 2018). MacDonald's (2018) non-traditional student definition is a person who meets any one of the following criteria: be at least 25 years old, attend school part-time, work full time, be a veteran, have children, wait at least one year after high school before entering college, have a GED instead of a high school diploma, being an FGS, are enrolled in non-degree programs, or have reentered a college program. Using enrollment patterns, financial status, and high school graduation rates through persistence and retention, the National Center for Education Statistics (n.d.) defines a non-traditional learner as any person who displays the following attributes: delayed in enrolling in post-secondary education more than one year after graduating high school (enrollment patterns), have dependents other than a spouse, be a single parent, work full time while enrolled, be financially independent of parents (financial status), or attain a GED (high school graduation status). Such definitions are not age-dependent and include several environmental, work, and family influences in determining the meaning of a "non-traditional" student. Moving forward, this study will refer to "non-traditional" and "adult learners" interchangeably without inferring any difference in population. Additionally, this study will assume MacDonald's (2018) "non-traditional" definition moving forward throughout this study.

Virtual Reality in Education, Training, and Learning

While the use of technology in higher education, like online learning, to deliver formal academic curriculum and skills training to both traditional and non-traditional students is not a new concept, much of the evaluation does not include VR as a process in education assessment or the design and delivery of curriculum (Hamilton et al., 2021; Jensen & Konradsen, 2018; Radianti et al., 2020). Currently, only 80 published studies include empirical, qualitative, or quantitative analysis containing a theoretical framework to assess learning outcomes of college students based on VR curriculum delivery systems; that number dropped to less than 60 when the researchers only evaluated IVR studies (Radianti et al., 2020). While VR technology remains emerging in most industries, accessibility studies were performed as early as 2014 to determine its applicability in training sessions (Jensen & Konradsen, 2018). In their reviews of VR-based studies, Jensen and Konradsen (2018) and Radianti et al. (2020) found that as VR hardware became more accessible in the last 10 years and software programs more relevant, several studies began testing participants' program knowledge using VR metaverse simulation techniques.

Studies using the newest developments of 3-D technology, like those in VR, allowed students to change the software's interface in real time, interact with others in a chat function, and move through a 3-D metaverse (world) to experience the environment (Dickey, 2005). That said, using immersive experiences that stimulate human sight and sound to deliver new knowledge has occurred since the 1960s. Ivan Sutherland (1965) formulated an experience using immersive sight and sound by creating a stereoscopic display through an HMD. While rudimentary, the device provided a type of immersion experience to provide a false sense of depth while looking through glasses at an object. Building from this technology, the United States Air Force created the first flight simulator using VR-integrated computer science research (Barnard, 2022). The U.S. military cornered the VR market, creating more immersive flight simulators that would link multi-users into one experience in the 1990s. While VR, AR, and IVR technology emerged in computer science and military training, video game companies and social media sites began producing the first commercial HMD VR experiences in the mid-2000s (Barnard, 2022; Sherman & Craig, 2019).

Pushed by the online learning curriculum blossoming on college campuses, educators and research scientists in the 1990s began to explore how VR, AR, and IVR could aid in delivering educational content by exploring the concept of presence and immersion as an online educational delivery tool (Psotka, 2013; Slater & Wilbur, 1997; Witmer & Singer, 1998). The 2000s provided education researchers with game-like VR software and hardware, and in the following decade, VR became an affordable consumer good (de Freitas & Oliver, 2005; Dickey, 2005). VR began to emerge as an alternative to online learning for hands-on training, specifically in the medical, engineering, and construction industries (Feng et al., 2018; Lee & Wong, 2014; Pan et al., 2016; Psotka, 2013; Ruthenbeck & Reynolds, 2015; Wang et al., 2018). In the past two years, VR researchers have begun investigating VR as an educational tool that includes learning assessment and student success outcomes (Fischer et al., 2021; Mori et al., 2022). While research involving VR, IVR, and AR as education delivery tools is still emerging, using such technology in corporate training and college courses requires a methodological framework for a practical, effective, and assessable VR learning experience.

The Elements of an Effective Virtual Reality Learning Experience

Kafai and Dede (2014) provide four distinct reasons why VR, IVR, and AR offer unique learning experiences not readily found in other online or distance learning environments for any student. First, learners can manipulate micro-worlds not readily accessible in the real world. Second, participant learners experience "real-time" social interaction to explore personal identity even when physically apart. Third, interactions between participant learners in the virtual world can be highly engaging and motivational.

Fourth, virtual worlds can be closed educational "classrooms" within a controlled learning environment, allowing formative and summative assessment. Creating an immersive learning environment using VR stimuli and separating the participant from actual reality makes a unique learning experience that interrupts the traditional instructional process and assists a student’s learning ability (Bricken, 1991; Sherman & Craig, 2019).

Deploying realistic software to deliver curriculum is integral to creating an authentic learning atmosphere within the VR framework (Pan et al., 2016; Sherman & Craig, 2019). With that said, the IVR curriculum delivery framework has two unique components to view a learning experience separate from other technological (non-immersive VR and 2D computer-generated) learning experiences (Sherman & Craig, 2019). First, the experience must be interactive in that the student must use physical mobility with direct action to interact with components of the virtual experience. Second, the experience must be immersive, so the participant feels present within the virtual experience with a suspended sense of actual reality (Psotka, 2013; Sherman & Craig, 2019). For IVR to deliver curricula successfully, it must be so realistic that the participants lose control of their perception of actual physical reality. Also, the type of VR hardware matters when achieving a wholly immersive experience; several different types of VR hardware are available to the consumer. Marrying the correct technical device with the proper software to deliver instruction is essential to creating a proper learning environment in VR (Dickey, 2005; Kafai & Dede, 2014; Sherman & Craig, 2019).

Understanding the physical limitations of an educational environment while creating learning content explicitly for students’ learning ability is best performed when educators understand the parameters of VR hardware and software design specific to curriculum delivery (Dickey, 2005). There are several different categorizations of augmented and virtual world technology and devices: VR HMDs, desktop VR applications, AR, and cave automatic virtual environment (CAVE) (Jensen & Konradsen, 2018; Radianti et al., 2020; Sherman & Craig, 2019). VR HMD devices are goggles covering the eyes that track the body's movement in real time and physical space using an LCD screen (Hamilton et al., 2021). Desktop VR applications and software are commonly seen in realistic video games where users can interact with a 2-D alternate reality on their desktop or laptop (Feng et al., 2018). AR uses glasses and other devices to provide a virtual, augmented aspect of reality, like placing an object in a real-world living room through a computer or phone application (Sherman & Craig, 2019). CAVE devices provide a life-like screen showing a differing view of reality and surrounding the user, while goggles or glasses allow interaction (Jensen & Konradsen, 2018).

Both CAVE and HMD enable a virtual metaverse experience within the viewing space; however, by eliminating the perception of actual reality, HMD hardware physically immerses the user entirely in an alternate reality without additional equipment other than the HMD goggles (Hamilton et al., 2021; Jensen & Konradsen, 2018). Alternatively, AR uses technology to supplement reality without allowing the user to detach from that reality and enter a complete alternate reality (Jensen & Konradsen, 2018; Radianti et al., 2020; Sherman & Craig, 2019). Each VR hardware configuration aligned with specific software creates a different learning experience. The combination of hardware, software, the ability to produce the desired learning environment, and a well-designed and delivered curriculum are integral parts of a successful experience for students learning in a VR environment (Bricken, 1991; Castaneda & Pacampara, 2017; Dickey, 2005; Hamilton et al., 2021; Pan et al., 2016; Psotka, 2013).

A well-designed and delivered curriculum complements the use of proper hardware and software to deliver a successful IVR, VR, and AR learning experience (Sherman & Craig, 2019). Unlike an online or traditional classroom learning atmosphere, technological hiccups can disrupt learning in the VR classroom (Jensen & Konradsen, 2018; Radianti et al., 2020; Sherman & Craig, 2019). Creating an IVR metaverse classroom relies on the ability of the metaverse creators, participants, and VR software and hardware to create a learning environment where technology is not a hindrance but a value-add (Sherman & Craig, 2019). Lagging graphics, unrealistic human depictions, and intermittent disruptions in software and teaching while delivering the immersive experience moves participants out of alternate VR reality, breaking the VR experience's immersive presence and disrupting the learning experience (Castaneda & Pacampara, 2017; Pan et al., 2016; Sherman & Craig, 2019).

AR, VR, and IVR technology challenge the definition of a traditional learning environment by suspending actual reality to create an alternative real-time immersive learning paradigm (Dickey, 2005; Sherman & Craig, 2019). Immersion presence, where the body reacts to the new virtual reality instead of the everyday reality, is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, p. 225).

A VR immersive learning environment creates a significantly different classroom experience than any other 2D online or traditional in-person classroom experience (Dickey, 2005; Kafai & Dede, 2014; Sherman & Craig, 2019; Witmer & Singer, 1998). The immersive environment must contain the opportunity for interactivity to achieve a fully immersive presence within the VR classroom and for the participant to be so mentally immersed in IVR that they may fully absorb mentally stimulating content while disregarding actual reality stimuli (Sherman & Craig, 2019; Witmer & Stinger, 1998). Therefore, the level of immersion depends on the ability of the metaverse (VR) environment to remove actual reality from participants' perceptions thoroughly, allowing the participant to entirely lose the concept of actual reality while physically interacting with elements within the metaverse (Radianti et al., 2020; Witmer & Stinger, 1998).

Andragogy and Online Curriculum Design and Delivery

Online curriculum delivery systems are robust in many higher education institutions; however, very little research explicitly details the effectiveness and quality of an online course delivery system using IVR technology and discussing immersive presence as a learning tool targeting, specifically, adult learners (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Radianti et al., 2020; Sherman & Craig, 2019). While VR experiences are still considered experiential, they are an opportunity to provide a learning environment incorporating many elements of traditional teaching: field trip experiences, group discussions and interaction, hands-on learning, and concept visualizations (Bricken, 1991). While VR may create an exceptional immersive environment equipped for learning and teaching, successful curriculum implementation in an immersive VR environment is integral to creating an optimal learning experience for adult learners (Castaneda & Pacampara, 2017; de Freitas & Oliver, 2005).

Adults are self-directed learners who want to take responsibility for their learning. Knowles's (1984) theory of andragogy suggests adult learners are motivated to learn when they see the relevance of the content to their own lives and when they can apply what they learn immediately to solve problems or meet their own needs. Creating a supportive and collaborative learning environment where adult learners can share their experiences and learn from each other is a crucial concept in andragogy, believing that adults learn successfully when actively involved in the learning process (Knowles, 1984).

Andragogy is the practice of teaching and developing a curriculum for adult learners (Knowles, 1984). Unlike pedagogy, which focuses on children's learning and its assessment, andragogy is based on adult learners' specific learning needs and characteristics. When developing a curriculum for adult students, educators must consider their prior experiences, motivations, and learning styles, as well as their goals and expectations (Castaneda & Pacampara, 2017; de Freitas & Oliver, 2005; Kafai & Dede, 2014; Knowles, 1984; Sherman & Craig, 2019). According to Knowles's (1984) research, adults are self-directed and desire to participate actively in their learning. They also have a wealth of life experiences and prior knowledge from which they can draw in the learning process, and they need to see the relevance of new information to their own lives and experiences.

Knowles (1984) developed six core learning principles driving adult learning. The first principle is the idea of self-conception. Adult learners have an independent self-concept where the need to take an active role in their learning is vital. The second principle involves the adult learner's past knowledge and experience. Adults have many life experiences and prior knowledge to draw upon in the learning process. The third principle involves the readiness to learn. Adults are often motivated by a need to address specific problems or goals and see new information's relevance to their lives and experiences. The fourth principle details the adult's orientation to learning. Adult learners are task-oriented and want to apply what they learn almost immediately to real-world situations. Fifth, adults are intrinsically motivated to learn, and they need to see how learning will benefit them in achieving their goals. Sixth, adults learn more successfully when learning is internally motivated.

By considering these six core principles, educators can create more effective and engaging learning experiences adjusting to best practices for adult learners (Knowles, 1984). For example, the curriculum can provide opportunities for self-directed learning, hands-on learning, problem-solving, and design learning experiences relevant to adult learners' lives and experiences. Knowles's (1984) six core learning principles in andragogy emphasize the importance of recognizing and building on adult learners' unique characteristics and needs in designing and delivering an effective learning experience.

Several studies illustrate andragogy in education and curriculum design and delivery in various industries. O'Neil et al. (2017) describe strategies for incorporating active learning strategies, such as case-based learning and simulations, into online nursing education.

The study emphasizes the importance of creating a learner-centered online environment that promotes engagement, interaction, and collaboration while tailoring course content to adults' unique needs and preferences. Palloff and Pratt (2013) emphasize the importance of creating a learner-centered engagement that encourages interaction and collaboration among learners and discusses strategies for developing coursework online. Learner engagement is a critical component of developing a curriculum to engage adult learners and is one of several critical points in Knowles's (1984) andragogy theory.

VR technology is poised to meet the demands of delivering the curriculum through an andragogical framework. VR can deliver immersive, personalized, and experiential learning content to students to meet the needs of an andragogical learning framework through personalized instruction and experiential learning and offer simulated learning using actual-world learning content (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Radianti et al., 2020; Sherman & Craig, 2019).

Since IVR is a technology that allows learners to engage with simulated environments that feel real and immersive, its use in education has the potential to support the main andragogy principles. IVR provides a highly engaging and interactive learning environment that is appropriate for adult learners, who are more often more motivated to learn when they are actively engaged in the learning process (Castaneda & Pacampara, 2017; de Freitas & Oliver, 2005; Kafai & Dede, 2014; Knowles, 1984; Sherman & Craig, 2019). Lastly, IVR can allow learners to engage in problem-solving activities and simulations that are realistic and relevant to their personal or professional goals (Knowles, 1984).

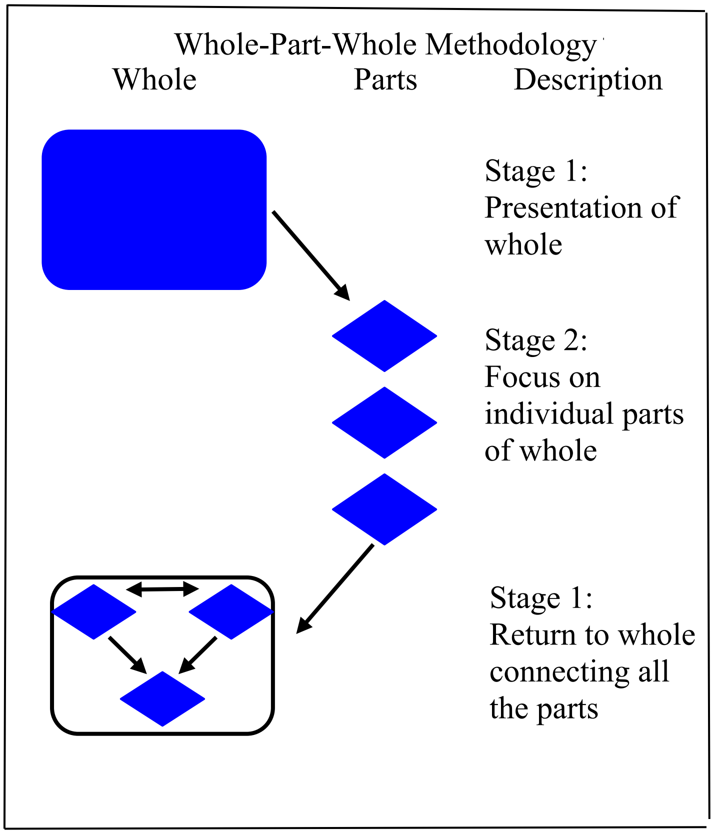
VR emphasizes the importance of analyzing the adult learners' needs and characteristics while developing a curriculum that creates an opportunity to assess learning outcomes based on both (Castaneda & Pacampara, 2017; de Freitas & Oliver, 2005; Kafai & Dede, 2014; Sherman & Craig, 2019). Using Knowles's (1984) andragogical learning theory within the IVR curriculum delivery technology, adult learning (non-traditional) students still require an intentional and specific curriculum delivery framework. The whole-part-whole (WPW) learning theory applies to curriculum development to create effective and efficient student learning experiences (Swanson &

Law, 1993). The theory suggests that students are initially presented with a complete skill or concept, then, the concept is broken down into smaller parts for focused practice, and finally, the concept integrates those parts back into the whole concept (Swanson & Law, 1993). In curriculum development, the WPW approach is particularly effective with complex and challenging topics.

It allows students to gradually build their understanding, starting with a big-picture view of the instruction before breaking up the lessons into manageable smaller parts. Reassembling those parts back into the "whole" of the concept allows students a better mastery and retention of material, leading to more successful learning outcomes (Swanson & Law, 1993). The WPW learning theory has been applied in various fields, including physical education, psychology, and education. In curriculum development, the theory can be used to design effective learning experiences for all students. According to the WPW approach, learners should initially be presented with a complete skill concept, breaking that concept down into smaller parts for focused study and practice and finally integrating those parts back into the "whole" skill or concept. This approach can be particularly effective for complex or challenging topics as it allows students to build their understanding gradually, starting with the big-picture view before diving into the details (see Figure).

Figure

Whole-Part-Whole Learning Methodology



Note. Adapted from "Whole-Part-Whole Learning Model," by R. Swanson and B. Law, 1993, *Improvement Performance Quarterly*, *46*(1), p. 44 (https://psycnet.apa.org/doi/10.1111/j.1937-8327.1993.tb00572.x).

Immersive Virtual Reality and Learning Outcomes

In VR research, assessing learning outcomes that use commonly accepted learning theories like behaviorist, cone, contextual, game-based, generative, active, and experiential learning, or Jeffries simulation is scarce (Radianti et al., 2020). Qualitative research methods are sparingly used as a framework of analytical data collected by questionnaires or tests and account for only 22% of current IVR educational assessment research studies; almost half (46%) included no assessment methods (Radianti et al., 2020).

Additionally, the research of both Jensen and Konradsen (2018) and Radianti et al. (2020) reviewing VR studies in training and education concluded that most studies mixed both non-traditional and traditional or K-12 students using various VR applications (immersive, online, desktop VR) in their research. To that end, empirical studies assessing VR in education are relatively new, no matter the student population. One example is Lee and Wong's (2014) study describing how students who used a desktop (non-immersive) VR system had better or equal test scores on a biology test identifying a frog's body parts than those provided only in a PowerPoint lecture.

While research institutions use VR and, even more specifically IVR, curriculum delivery systems to provide hands-on training, few have verified assessments for student learning outcomes (Jensen & Konradsen, 2018; Radianti et al., 2020). For example, medical schools have successfully utilized VR to simulate surgical lab experience (Fischer et al., 2021; Radianti et al., 2020; Ruthenbeck & Reynolds, 2015). Using VR, simulated online medical training allows medical schools to deliver instruction without risking human life and reduces lab and surgical suite use costs. Generally, using VR in medical school instruction is relegated to simulated procedures to assess the practical application of actual surgical procedures on human subjects (Mori et al., 2022; Ruthenbeck & Reynolds, 2015).

Assessment of technical procedures routinely evaluates only technical and physical skills in the performance of technical and physical tasks. Such studies rarely assess the student's learning ability by applying established learning theory to instruction and performing any formative or assumptive assessment (Mori et al., 2022). While

Makransky and Lilleholt's (2018) research discovered improved test scores when a student used a VR tool to analyze biological DNA in a simulated laboratory, the VR tool was used as an "add-on" to support another curriculum. Still, VR is still not widely accepted as a stand-alone curriculum delivery system in online education.

The immersed experience within an IVR environment allows participants to learn new skills in typically unsafe environments for beginners, like a chemistry laboratory or metal welding task on top of a high-rise office building (Freina & Ott, 2015). IVR allows students to gain skills and knowledge in areas that typically create a high level of human risk or higher physical facility costs when performed in a traditional lab or classroom environment (Ruthenbeck & Reynolds, 2015; Sherman & Craig, 2019). For example, Feng et al. (2018) evaluated participants using IVR to train engineers in better ways to assist in proper emergency building evacuations. Although Feng et al. (2018) reported learning outcomes by analyzing participants' evacuation best practices, self-protection skills, and spatial knowledge, the research also heavily considered psychological and behavioral trends seen in participants during the IVR training simulation, like fear, engagement, stress, and mental workload deficiencies but did not relate the psychological and behavioral factors back to learning outcomes. A study by Wang et al. (2018) critically reviewed VR and AR applications in construction engineering, education, and training; such training involves engineering principles of building construction design and emergency preparedness.

The studies of both Feng et al. (2018) and Wang et al. (2018) provided a safe and secure area in VR for participants to train and learn engineering construction principles without risk to human life or using expensive physical (tangible) construction sites.

Generally, research studies utilizing VR as a curriculum delivery methodology revealed no assessment of student learning outcomes using learning theory other than the perception of completing hands-on virtual tasks related to the participants' industry (Feng et al., 2018; Mori et al., 2022; Wang et al., 2018). These studies incorporated learning assessment in their analysis of the effectiveness of VR and IVR. They routinely used VR as an add-on tool that did not synchronously teach instruction in a metaverse environment. The meta-analysis of VR's use in education and training by Radianti et al. (2020) found that most studies used VR as a developmental training tool, not a curriculum delivery method. Many studies did not assess learning outcomes or incorporate learning theories using VR equipment. In contrast, science-based cognitive studies using immersive VR technology with proper learning outcome assessment did show better student learning assessment outcomes than non-technology curriculum delivery systems (Johnston et al., 2018).

Theoretical Framework

Dewey (1916), Vygotsky (1930–1934/1978), Piaget (1954), and Bruner (1961) are all constructivist theorists who have contributed to the theoretical framework. They share many commonalities; however, each theorist has a unique perspective regarding how learners interact with their environment and construct meaning resulting in knowledge and learning. Piaget's (1954) theory of constructivism emphasized the role of individual cognition in learning. He argued that learners actively construct knowledge by engaging with their environment. The process is influenced by the learner's cognitive stage of development: the sensorimotor, preoperational, concrete operational, and formal operational stages. While agreeable that learning is an active process, Vygotsky (1930–

1934/1978) theorized that constructivism must include social interaction, adding the intersection of peers and societal influence with learning. Bruner’s (1961) theory of constructivism emphasizes the importance of context and culture in learning. He argued that learners construct meaning by building upon prior knowledge and that this process is influenced by the social and cultural context in which learning occurs. Bruner (1961) believed that learners actively construct new knowledge through a discovery process and that the instructor’s role in facilitating that discovery process is integral to learning. Lastly, Dewey’s (1916) theory of constructivism centered on the importance of experience in learning. He argued that learners construct knowledge by reflecting on their experiences and that education should focus on problem-solving, critical thinking, and reflection.

Constructivism is a theoretical framework emphasizing the learners’ role in actively constructing their understanding and knowledge through social experiences and interactions (Bruner, 1961; Piaget, 1954; Vygotsky, 1930–1934/1978). Specifically, learners are seen as present and active participants in absorbing knowledge, where engagement in processing and constructing meaning and knowledge lies at the base of intelligence. Constructivism informs education, specifically IVR, by recognizing that learners construct knowledge through experiences and interactions with their environment.

IVR provides an immersive environment where learners can explore simulated real-life environments to actively participate in learning and create new experiences as a base for new interaction. Webb (1980) summarizes Piaget’s learning theory when she suggests that learning is a series of thought assimilation and accommodation.

New knowledge must assimilate with experience, enabling the psyche to accommodate new knowledge as a student creates new schemas (experiences). Ultanir (2012) concludes that constructivism is an idea that pushes the learner to develop "meaning making" from new knowledge (p. 196). Knowles (1984) builds on this premise by specifically directing instructors who create curricula for adult learning by relating new knowledge to old experiences as a pathway to cement new learning and theoretical understanding. Utilizing social constructs and past experiences while coupled with the delivery of new information, the ability of the student to accept new knowledge through her own past experiences is how constructivism intersects with curriculum development for adult (non-traditional) learners (Knowles, 1984; Ultanir, 2012).

Summary

Little research successfully addresses VR technology's applicability to meet curriculum outcomes for adult (non-traditional) students through theoretical frameworks and adult learning theory lenses. As VR technology emerges through continued and better software and hardware design, the potential to reach populations of adult learners with instruction usually relegated to only onsite and in-person laboratories increases. Even as an emerging technology, IVR creates a curriculum delivery vehicle that allows Knowles's (1984) theory of andragogy through the six core adult learning principles structurally framed for the successful delivery of adult learner instruction. While Knowles's (1984) six core learning principles address curriculum delivery, the constructivist theory provides a theoretical framework for students' learning and education, and the WPW learning theory (Swanson & Law, 1993) provides a teaching framework embedded in this study's methodology.

Chapter 3 – Design Research and Methodology

This quantitative study is designed to examine the potential effect IVR has on student outcomes when used to teach non-traditional students. This chapter will discuss the research design, study participants, population and sample selection, data collection procedures to include both research questions, data analysis, ethical considerations, and limitations in the study's design. A constructivist theoretical framework informs the study, and the curriculum administered follows in alignment with an andragogical learning theory in both design and delivery.

Research Design

This research project is an experimental study investigating the intervention of an IVR delivery tool on learning outcomes when teaching a hard-science curriculum to non-traditional adult learning students. After determining participants' eligibility and gaining demographic data, participants were provided a pre-test to determine their baseline understanding of animal cell biology. Participants were randomly assigned to either the control (non-VR) or experimental (VR) learning method group. Instruction was delivered to both learning method groups via a lecture within either an IVR metaverse or through an online 2-D online classroom like Zoom, WebEx, or Microsoft Teams. A post-test followed both groups' lectures to evaluate participants' learning outcomes. Analysis of the data included coding survey responses using nominal codes and assigning a grade to each test, indicating the number of correct answers.

Research Questions

This study addresses the following research questions:

1. How effective is immersive VR technology compared to conventional classroom delivery methods for adult learning (non-traditional) students studying a hard-science curriculum?
2. What is the difference in test scores between adult students who study science in a VR and a non-VR learning environment?

Study Participants, Population, and Sample Selection

All eligible participants for this study were non-traditional students, as defined by MacDonald (2018), and enrolled in an undergraduate or graduate academic program. Participants were sourced through announcements at local higher education institutions and social media. All participants were recruited by online advertising, word of mouth or personal connection and each participant voluntarily made the decision to participate. Participants identified their non-traditional adult learner status through an online survey (Appendix A) to establish eligibility. 60 eligible participants were randomly assigned to two learning method classrooms: IVR and 2D online. Each participant gave informed consent and was aware of their right to withdraw from the study at their leisure. Before recruiting participants, this study was approved through Frostburg State's IRB protocol.

Data Source and Collection Procedures

As students inquired about participating in this study, they were randomly assigned a unique two-digit numerical participant number. To evaluate participants' eligibility to join this study, a survey was administered to establish their eligibility as non-traditional (adult learning) students. If the participant was deemed eligible, a second survey was administered, asking specific non-identifying demographic questions (see Appendix B). The participant number was used to link the surveys together without any information linking the participant's identity to any study document.

Before either group was provided the curriculum, both learning method groups began their class in a 2D online Zoom room. The instructor provided the pre-test link using the Zoom chat function. A ten-question knowledge baseline pre-test covering topics in the curriculum was administered. Participants were not provided results, and the instructor did not provide feedback. Once each participant completed the test, and for those participants assigned to the IVR learning method, the IVR metaverse classroom was opened, and participants joined the class to begin the lecture. For participants assigned to the 2D online learning method class and immediately after the pre-test was administered, the classroom lecture began.

The curriculum was framed by Knowles's (1984) theory of andragogy and Swanson and Law's (1993) WPW curriculum delivery approach. The lecture began when the instructor briefed all participants on the expected outcomes of the lecture:

- To identify and understand the basic anatomy and components of an animal cell.
- To understand and explain how each of the components of an animal works together within the cell, and
- Identify the steps of creating mRNA strands from DNA code to produce proteins that feed the animal cell.

Before the class in the VR learning method began, a short instruction on how to operate the VR controls, specific to the metaverse learning environment, was provided to every participant. Once participants were comfortable in the IVR classroom, the curriculum was delivered; throughout both classes, the instructor provided a live online synchronous learning experience to participants who received information about the animal cell and the components and procedures in which DNA is transcribed and translated into mRNA code (see Appendix D).

Immediately following the lecture, the instructor paused for questions. In the 2D online learning method group, the instructor placed the web address for the post-test using the chat format. Participants completed the post-test at their leisure and once all participants exited the Zoom room, the instructor closed the class. Following the lecture in the IVR learning method classroom, participants were encouraged to utilize the features of the metaverse classroom and engage with the VR animal cell. Once completed, participants went back to the Zoom room to receive the post-test link in the chat function and take their post-test. Once all participants took their post-test, the instructor closed both the Zoom room and the metaverse classroom. Data collected included survey results and the results of the pre and post-tests. Both tests included the participant's unique non-identifying participant number to connect the survey and testing data together, but not directly back to an individual participant.

Instrumentation

Instrumentation for this study included survey data, two tests (pre and post lecture) and the curriculum delivery vehicle. The baseline knowledge pre-test consists of a ten-question exam covering information in the curriculum and consisting of multiple choice (2), fill-in-the-blank (4), and open response (4) was administered. The curriculum delivery is provided by either a head-mounted (HMD) Meta Oculus Quest 2 VR device in an immersive environment delivered by third-party software (Engage™) or a traditional online lecture using a PowerPoint (see Appendix D). The VR technology utilized as a curriculum delivery tool provides instruction via a wireless internet connection through a

Meta Oculus VR HMD VR or any immersive VR HMD owned by the participant and could operate the metaverse software.

The immersive VR metaverse was created by a third-party firm, Lobaki, Inc. Lobaki, Inc. is a software development firm trained to develop and deliver IVR experiences in education to HMDs like the Meta Quest 2. The participants randomly assigned to the 2D online learning method received a synchronous live lecture via PowerPoint using an online platform such as Zoom, Microsoft Teams, or WebEx. Participants are encouraged to use their own VR HMD to participate in the IVR learning method experience; however, VR software and hardware are provided if a participant needs one to participate and are physically located near the instructor in actual reality. Participants were expected to utilize their own computer and internet connections for participation in the 2D online learning method.

Data Analysis Procedures

Survey data were coded using a nominal scale to easily analyze results. The following codes were used for survey responses: No = 0, Yes = 1, Male = 0, Female = 1, and questions with Likert Scale-type responses received a code of 0-5, depending on the number of answers provided. Participants were able to not answer any question they chose, and those answers were recorded as n/a and left blank in the dataset. Each pre and post-test was scored based on correct answers and a percentage of those correct answers was recorded for analysis. The total potential points possible on any test was 13 with individual questions ranging from 1 to 3 possible points. The instructor graded each test and assigned points based on the participant recording a correct answer to a question. Test scores from the control and experimental group participants were analyzed using repeated measures ANOVA using regression approach.

The statistical modeling approach was utilized to build a model to address the research questions (Vik, 2014). Building a repeated measures ANOVA model using this approach allowed us to incrementally add continuous or categorical predictors or their interaction terms. Using a statistical model comparison approach, we can test to see whether individual predictors improve the model by significantly decreasing the model error by isolating each effect.

Validity and Reliability

This study heavily relied on the ability of the participants to operate the VR hardware and interact with the VR software provided. Frustration or the inability to appropriately interact within the IVR metaverse would cause a break in mental immersive presence, invalidating the participant's experience and excluding the participant from the study. No participant dropped from the study and there were no complaints of motion sickness or the inability to operate any of the equipment provided. No other participant complaints were recorded during the study.

Since the instructor graded each participant's exam, (pre and post), this study was subjected to grading bias. To reduce the potential for bias, a second researcher rescored 20% of all exams, split evenly among the pre-and post-tests. The second researcher was provided a random list of 24 completed tests, which was determined by using a random online number generator to identify participant numbers and their related tests. Once 24 numbers were randomly generated, the instructor provided the second researcher with the tests and an answer key to grade each test. Results from the second researcher's grading entries were compared to the instructor's grading entries. Finally, to establish reliability this study computed the interrater reliability estimate.

Role of Researcher

The study employs the researcher as the one and only curriculum instructor. The researcher has little to no background in the analysis of biology, DNA, and mRNA and delivered the curriculum as written. To validate the curriculum as sound biological science, the curriculum was reviewed and approved by Dr. Sybil Gotsch, a research biologist and Associate Professor of Biology at the University of Kentucky. Dr. Gotsch is also the founder of Gotsch Labs, an in-the-field biological lab in Costa Rica, South America, and has been teaching in the field of biology at a higher education level for over 20 years.

Measures of Ethical Protection

This study did not begin until all IRB and Frostburg State University policies required were followed and the proposal for study with human subjects was approved. All participants were notified through written and confirmed consent that their involvement was voluntary and that they could leave the study for any reason. All study results were provided to each participant upon their written request.

Chapter 4 – Findings

This chapter presents the results of this study that examined the effects of an emerging curriculum delivery technology (IVR) on students' learning outcomes. Using a repeated measures ANOVA regression approach, this study analyzed the effect of using an IVR classroom to deliver a science curriculum to non-traditional students. The study compared their learning outcomes with a traditional online class. This chapter begins by reiterating its research questions and describing the participants and the study measures, followed by a presentation of the statistical analysis and the main finding.

Research Questions

The study addresses the following research questions:

1. How effective is immersive VR technology compared to conventional classroom delivery methods for adult learning (non-traditional) students studying a hard-science curriculum?
2. What is the difference in test scores between adult students who study science in a VR and a non-VR learning environment?

Descriptive Statistics

The study participants were 60 non-traditional students enrolled in at least one academic credit at a college or university. The sample consisted of 44 females (73%), 15 males (25%), and one participant who chose not to identify their gender. The age of all participants ranged between 18-55 years old, with one participant indicating they were older than 55 years. Six participants were enrolled in an associate degree (10%), 23 in a bachelor's degree (38%), 26 in a graduate degree (43%), and five in a terminal degree program (8%) (see Table 1).

Table 1

Descriptive Statistics by Degree Level

	Associates	Bachelor's	Master's	Terminal
Gender identity				
Male	1	7	5	3
Female	5	15	21	2
N/A		1		
Total	6	23	26	5
Age range				
18–25	1	1	1	0
26–35	0	4	4	1
36–45	2	10	11	1
46–55	2	8	10	3
55+	1	0	0	0
Total	6	23	26	5

Interrater Reliability

To ensure the interrater reliability, a second researcher scored 20% of the exams (10% of total pre-tests and 10% of total post-test). The interrater reliability estimates using the Intraclass Correlation (ICC) were computed. The ICC value of 0.75 indicated a 'moderate to good' reliability.

Main Analysis-Repeated Measures ANOVA Using Regression Approach

The dataset was prepared for analysis by assigning numerical codes to the dependent group (Non-VR= 0) and the independent group (VR = 1) and their variables. This coding process allowed for an efficient and structured data analysis. A repeated measures ANOVA using regression approach was used to analyze the effects of the VR intervention on students' learning outcomes. This statistical modeling allowed for comparing baseline (simple) and final (complex) models. The outcome variable in this study was the online learning control group's test scores collected by both the pre and post-test assessment. One of the predictor variables was time (i.e., test scores collected by the pre and post-test assessment) and the second predictor was the learning method. The analysis was performed using R software version 4.2.2 (R Foundation, n.d.) and RStudio (Posit, n.d.).

Baseline Results

We compared the pre-test scores between both learning methods to show that each participants received the same base of knowledge, $t(55) = .60$, $p > .05$ where the IVR learning method $M = .17$ and the 2D online learning method $M = .20$ (see Table 2). Given that no true significant difference in means at a 95% interval was detected, we concluded that deeper analysis was needed and used a regression approach to establish a baseline model.

Table 2

Mean and Standards Deviations of Test Scores by Learning Method and Time

Learning Method	Pre-Test *M* (*SD*)	Post-Test *M* (*SD*)
Online Learning	.20 (.19)	.62 (.23)
Virtual Reality	.17 (.14)	.63 (.20)
Combined	.19 (.17)	.63(.21)

Change Over Time

Hypothesizing that post-test scores would increase over pre-test scores post-instruction in either modality, a baseline model (Model 1) was utilized to analyze the data using a regression approach. We created a weighted difference score by combining pre and post-test scores into a single outcome score. Each score was first multiplied by contrasted weights ($\lambda_1 = +1;\ \lambda_2 = -1$). This model performed fundamental analysis using the mean from both pre (M = .19, SD = .17) and post-test (M = .63, SD = .21) scores. Results indicated that the participants significantly gained knowledge from the instruction provided without consideration of the modality in which the instruction was delivered, $M_{diff} = -.31$, $t(59) = -14.3$, $p < .001$. Since the results from Model 1 indicated that participants gained knowledge through curriculum delivery over both modalities, the need to identify any significant effect the VR intervention had on learning outcomes was supported.

Main Effect of VR Status

Model 2 utilizes the learning method as a predictor within its framework, detailing outcomes regarding the main effect of the learning method on the weighted difference score (i.e., the difference between pre-test and post-test). The mean difference between VR group participants versus the online learning group participants was not statistically significant, $M_{diff} = -.03$, SE = .04, $t(58) = -0.58$, $p > .05$. The non-significant result indicates the null hypothesis that the learning method does not affect learning outcomes was accepted.

Main Effect of VR Status, Age, Gender, and Interaction Effect

While the learning method had no significant effect on participants' learning outcomes, Model 3 included two additional predictors: age range and gender, and their interaction. Like the results in Model 2, there was no significant effect on learning outcomes with VR intervention when factoring in age or gender; however, the analysis shows a slightly significant interaction between gender and some categories of age. The mean difference was the highest between female ($M = .09$) and male ($M = .38$) participants aged 18-25.

Model Fit for Final Model

A model comparison was conducted to determine if the interaction effect found between gender and age reduced the model error significantly.

This study compared a model (Model 2) that included VR, age, and gender with a model that included the interactions within those same predictors (Model 3). The results of the model comparison indicated that adding the interactions between age, gender, and VR did not positively impact the model; therefore, Model 2 had a better fit to the data and remained as the final model, $F(6, 54) = 1.46$, $p > .05$ (see Table 3 for regression coefficients for Model 2).

Table 3

Regression Coefficient Estimates for Model 2

Predictors	*b*	*SE*	*t*-statistic	*p*
(Intercept)	-.30	.06	-4.57	< .001
VR	-.03	.05	-.63	> .05
Age Range 1 (25–35 vs. 18–24)	.02	.06	.36	> .05
Age Range 2 (36–45 vs. 18–24)	.06	.06	.92	> .05
Gender	-.05	.05	-.85	> .05

Note. *b* represents unstandardized regression coefficients. *SE* represents the standard error for *b*. *p* represents the probability of *t*-statistic.

Chapter 5 – Conclusions and Implications

This study explored emerging technology's use to analyze adult students' learning outcomes in a hard-science curriculum. Specifically, this study used IVR technology to teach non-traditional students and assessed their ability to learn new knowledge. Ultimately, the study answered the research questions by analyzing participants' pre and post-test scores in differing learning methods–IVR and 2D online. While the results show no significant differences regarding the gain between pre and post-test scores between the VR and 2D online learning methods, the results do have implications for the effectiveness of IVR technology and the development and delivery of curriculum for adult learning in higher education. Additionally, the interaction of age and gender variables within the VR predictor was found to be significant. While this interaction was not included in the final model, it provides further insight into the assessment of learning using IVR for specific populations of non-traditional students. To that end, this chapter will discuss the implications of IVR in higher education teaching and learning outcome assessment and the importance of curriculum development specifically for non-traditional students by connecting the results with the previous research cited within the literature review. Lastly, this chapter discusses the study's limitations and potential future research topics stemming from these results.

Discussion of Results

A review of the literature surrounding VR research framed the methodology of this study. Radianti et al. (2020) and Jensen and Konradsen (2018) reviewed a comprehensive list of studies depicting VR use as a teaching or instructional tool.

Such studies only assessed learning as a solely tactical or practical skillset without wholly assessing learned knowledge. Also, they included skills assessment in construction techniques (Feng et al., 2018; Wang et al., 2018), surgical techniques (Mori et al., 2022; Ruthenbeck & Reynolds, 2015), and training and simulation (de Freitas & Oliver, 2005; Feng et al., 2018), but did not include assessment of new theoretical knowledge. Lastly, study by Allcoat and von Mühlenen (2018) contained methodology closely, but not entirely, aligned with this study's methodology. In Allcoat and von Mühlenen's (2018) research, participants learned about the plant cell utilizing three modalities (traditional, 2D online, and IVR). It assessed learning using pre- and post-testing results but did not incorporate a real-time instructor during instruction. Compared to Allcoat and von Mühlenen's (2018) work and unlike any other research in the literature review, this study uniquely provides a real-time instructor teaching a specifically developed curriculum for both the 2D online and IVR learning method groups. Such gaps in previous VR and online learning research framed this study's research questions and methodological approach to understand how VR can successfully deliver curriculum to non-traditional students.

Research Question #1 was, "How effective is immersive VR technology compared to conventional delivery methods for adult learning (non-traditional) students studying a hard-science curriculum?" Research Question #2 was, "What is the difference in test scores between adult students who study science in a VR and a non-VR learning environment?" The results of this study suggest that IVR has no significant differences regarding the pre and post-test result gain between VR and online learning methods. The lack of a significant effect on test scores using IVR combined with the positive difference in pre- and post-test scores overall suggest that the IVR intervention did no worse or better than the 2D online learning method. Furthermore, this result infers that mean test scores would remain the same regardless of modality. Ultimately, this study concludes that VR courses, designed and delivered using the parameters dictated in this methodology, can be as effective as any equally designed 2D online course.

Since the IVR intervention held no significance in the learning outcomes of the participants and the overall post-test scores increased over pre-test scores, it is reasonable to conclude that the effectiveness of the intervention modality (VR) in this study is not the sole analytical driver of successful academic achievement. Prior research supports this conclusion through several studies. Research suggests that courses that include clear learning objectives, active learning strategies, and opportunities for interaction and student engagement (Freeman et al., 2014; Stefani, 2009) have positive results. Using a well-designed curriculum strategy to achieve positive academic success is supported by Slavin's (2014) research. Slavin's (2014) article discusses the effectiveness of cooperative learning in promoting academic achievement and suggests that successful cooperative learning depends on curriculum design and delivery quality. This study's methodology promoted student engagement and interactive learning in 2D online and VR classroom experiences by incorporating specific and intentional andragogical curriculum design and a methodical WPW delivery approach.

Kafai and Dede (2014) provided four distinct reasons why VR creates learning experiences not found in other classrooms. This study's intervention, the IVR metaverse classroom, incorporated three of the four elements in its design. First, building an interactive animal cell within an immersive metaverse classroom creates learning experiences not readily found in other distance learning environments. Specifically, this study's participants assigned to the IVR metaverse learning method were able to manipulate animal cell structure, a phenomena Kafai and Dede (2014) describe as a "simulated phenomenon" (p. 522) because it could not be replicated in the 2D online classroom.

The second unique experience is the ability of the study's VR participants to experience real-time social interaction even when physically apart. This study perfectly demonstrates this aspect in that the participants in the metaverse VR classroom could speak in their human (true) voice while using their own avatar to interact with other participants and the animal cell classroom. In the rare case where only one participant was in the IVR classroom, the uniqueness of the synchronous live instructor delivering the curriculum through her avatar creates a real-time social interaction.

The third distinct reason VR, IVR, and AR offer a unique learning experience is the ability for the participant to interact with the VR metaverse. This study's animal cell IVR metaverse classroom allowed participants to engage with the DNA and mRNA translation and transcription (or any other cell element) by allowing participants to interact with the process itself: participants could "send" the single strand of translated DNA to be transcribed and were able to initiate the transcription process by interacting with the cell to initiative the transcription process by "calling" for the ribosomes. This experience could be replicated outside of VR, thus making the experience truly unique.

Lastly, Kafai and Dede (2014) describe the fourth reason for VR's uniqueness is that all the participant's communication and interaction within a metaverse VR world can be used for assessment. Any conversation or written texts can be recorded for further analysis post-experience. While the IVR metaverse classroom learning method in this study was capable of such communication and assessment, the study's methodology did not require recording verbal or written communication and, therefore, did not incorporate this functionality into its design.

Andragogy emphasizes the importance of relevance and practical application of learning for adult learners. The WPW approach intersects with andragogy in that it provides a framework that breaks down complex concepts into smaller, more manageable parts, allowing learners to see how each part contributes to a greater concept (Knowles, 1984; Swanson & Law, 1993). This study incorporates both theories by creating educational environments that celebrate learning autonomy and motivating students to learn, while creating engaging experiences from which to build knowledge and delivering instruction that breaks down a mainly unfamiliar and complex scientific theory. Each participant's post-test scores in both learning methods either increased or remained the same after the curriculum was delivered; none decreased. This study's results align with previous studies showing that a well-deigned and delivered curriculum within an engaging and interactive learning environment creates more opportunity for academic success, no matter the modality (Dorn et al., 2020; O'Neil et al., 2017). To that point, Dorn et al. (2020), addressed learning loss (negative academic success) due to the pandemic when well-designed traditional classroom instruction was replaced with curriculum that was disjointed, unstructured, and not engaging. Also, Castaneda and Pacampara's (2017) study found that when instructors put time limits on VR use in the classroom, students were hyper aware and felt less present in the lesson and, therefore, resulted in being less immersive, a key factor in IVR's ability to deliver curriculum (p. 7).

The IVR learning method, more than the 2D online learning method, provided the best opportunity to infuse andragogical and WPW learning approaches into the study. Knowles (1984) suggests that adults prefer a problem-centered or task-centered approach to learning that is focused on the availability to apply theory to practice immediately. While the instructor lectured within the IVR classroom, participants could explore all available animal cell metaverse elements. Due to the immersive environment, participants could easily engage with any element within the metaverse, deepening the feeling of immersion, engagement, and participation in the learning process, which are essential elements of a successful IVR learning experience for adult learners (Kafai & Dede, 2014; Knowles, 1984; Sherman & Craig, 2019). Creating an IVR experience using a well-designed and delivered curriculum may be an essential reason as to why the IVR learning method performed as well (or as worse) as those in the 2D online earning method. IVR incorporated the WPW learning approach so well, creating an interactive and engaging experience for students, that the opportunity for the student to succeed equaled the 2D learning method.

Understanding the steps for the DNA and mRNA transcription and translation process was a curriculum key learning objective in the study's well-designed curriculum. While the lecture specifically utilized the WPW to dissect the entirety of DNA and mRNA theory into understandable "parts," before reunited those parts back into the "whole," the VR metaverse classroom enabled participants to engage into a deep mental immersive presence during instruction. By creating mental immersive presence, the IVR metaverse classroom specifically increased students' engagement and interaction with the curriculum. Creating mental immersive presence provided a key component to advancing academic achievement for adult learners through VR (Bricken, 1991; de Freitas & Oliver, 2005; Kafai & Dede, 2014; Sherman & Craig, 2019).

Adult learners are more successful at absorbing information when they can autonomously learn. Autonomy is a critical component of the andragogy theoretical framework (Knowles, 1984). Participants in the IVR metaverse classroom were permitted to autonomously engage elements of the animal cell and DNA and mRNA process throughout the lecture. After the lecture, the instructor allowed "free time" for students to engage other participants, explore the metaverse or, in the case of the 2D online classroom, ask questions or review instruction. This critical aspect of the study's curriculum delivery methodology incorporated Knowles's (1984) third principle of adult learning: self-concept. Building on the study's well-designed and delivered curriculum, creating successful learning experiences using VR was a critical company of the study's results.

This study also adhered to its constructivist theoretical framework. Leaning heavily on Dewey's (1916) interpretation of constructivism, this study centered the importance of learning on the experience provided by the IVR metaverse classroom and the stackable knowledge participants gained through an andragogy-inspired curriculum design and a WPW delivery approach. Constructivism suggests that learners can create new knowledge by building upon prior knowledge and experience by actively interacting within their environment (Bruner, 1961; Dewey, 1916; Piaget, 1954; Vygotsky, 1930–1934/1978). The functionality of the VR metaverse classroom included the ability to interact with the DNA and mRNA process as the lecture was being provided inside the IVR metaverse classroom, aligning directly to the study's constructivist theoretical framework. Even disregarding the deliberate curriculum construction dictated by the theory of andragogy, the VR metaverse classroom's immersive design intentionally created the opportunity to explore and interact with other participants, the live VR instructor, and elements within the classroom. In other words, if the study removed the curriculum from the methodology, the immersive nature of metaverse classroom would still align directly with constructivism theory. The IVR metaverse classroom embodied constructivism's unique perspective regarding how students interact with their immediate environment and construct knowledge from its meaning (Bruner, 1961; Dewey, 1916; Piaget, 1954; Vygotsky, 1930–1934/1978).

Learning outcomes were analyzed in this study using a new and emerging technology–IVR–when teaching non-traditional (adult learning) students. While the null hypothesis was not rejected, there was a positive change in post-test scores compared to pre-test scores for all participants. This result indicates that students gained knowledge in both the 2D online and IVR classrooms; therefore, this study concludes that IVR is as effective (or ineffective) as any other 2D online learning method. Additionally, this study supports prior research stating that online courses and classrooms are only truly effective in creating successful academic achievement if the curriculum is well-designed and explicitly delivered to the student population in class (Hamilton et al., 2021; O'Neil et al., 2017). This study used an andragogical approach to curriculum design and the WPW curriculum delivery method (Knowles, 1984; Swanson & Law, 1993) and it successfully produced positive learning outcomes for non-traditional students using an emerging new technology in VR.

The constructivist theoretical framework is aligned with this study through the IVR metaverse classroom learning method, providing opportunity for students to construct their own understanding and knowledge of the animal cell through engagement and reflection. Utilizing a well-designed and delivered curriculum to deliver instruction, this study created a dynamic process of building and refining knowledge through experience, engagement, and social interaction (Dewey, 1916). Finally, the instructor in this study served as a facilitator and guide throughout the participants' learning process, a critical aspect of the constructivism theoretical framework (Bruner, 1961; Dewey, 1916; Piaget, 1954; Vygotsky, 1930–1934/1978).

Limitations

Limitations of this study specific to VR include excluding differently abled students from learning in an IVR metaverse classroom. VR requires the physical use of the upper body and for participants to have stable corrected or uncorrected vision. Other physical requirements include participants to withstand the HMD on their head and neck, physically. VR headsets and controllers can be cumbersome, affecting participants' ability to engage in tasks for the time period required by this study. Also, as in actual-world studies, a researcher cannot control for every possible variable. The same is true in VR studies, but additional factors must be considered, such as motion sickness or other physiological effects directly related to the exposure and engagement to immersive environment used in the study.

The study was limited in the number of participants it could recruit in the time required to complete this dissertation. While VR headsets are widely available, participants with personal computers far outnumber participants with VR headsets; therefore, recruiting participants in the experimental IVR group was cumbersome and time-consuming. Lastly, the potential for bias in participant selection exists. People more comfortable with technology may be more likely to participate in a VR study, no matter their random selection into the control or experimental groups. The study was promoted online and in social media as a "VR and Emerging Technology" study; therefore, those participants who may not be comfortable using new and emerging technology may not have volunteered, attracting a participant base who are more comfortable with the study's technology. As such, the potential that subjective bias was introduced in the participant selection process exists and may have skewed results.

The study's limitations also extend to the methodology of the research. As a purely quantitative study, its limitations include a narrow and niche data set using a pre-set array of variables and limiting the depth of analysis. Using only 60 participants with seven quantitative variables narrows the scope of the study and hinders the applicability to a more significant population. Lastly, the analysis did not include any qualitative variables. Feelings of frustration toward the technology or understanding participants' lack of knowledge using the hardware could impact participants' ability to learn and, therefore, their test scores and the results of this study. Monitoring eye tracking movements or measuring physiological signs of stress through observation or survey data was limited as the study's methodology and research design did not consider those qualitative variables.

Additionally, this study provided the pre-test directly before the lecture and then administered the same test directly after the lecture. Doing so limits the ability to account for actual learning outside of memorization, a direct argument against andragogy theory and constructivism theoretical framework used in the study. While the tests included varied question formats, it stands to reason that limiting the exam to this format forced less learning and simpler memorization. Lastly, and addressing the same point, this study invited adult learners to participate in the study without regard to their desire to learn basic biology. This unknown desire limits the study's ability to perform an authentic assessment of learning outcomes under the framework of andragogy and constructivism without considering the factors motivating the participants to learn.

Suggestions for Future Research

VR has already demonstrated its potential to enhance various aspects of education, from engagement and retention to simulation and visualization. Understanding how VR technology influences learning outcomes is both qualitative and quantitative. Future research should consider a longitudinal study encompassing a synchronous and live IVR instructor. Also, this study opens pathways for mixed-methods research to analyze qualitative and quantitative factors when assessing adult student learning outcomes. This future research could give insight into the applicability of using VR to teach students in a live environment and determine the limits of VR technology while collecting the participant's perception of VR in the higher education classroom.

Learning outcomes are a necessary identifier of academic achievement; however, VR has the potential to transform the way students learn and engage with educational content. Future research should consider analyzing levels of engagement in immersive VR metaverses to determine self-efficacy in participants' learning outcomes. This study's results have identified a significant gender and age interaction with the IVR classroom experience. Such results align with a study by Alghamdi et al. (2020), which analyzes self-efficacy in online learning, considering age and gender. Women had more self-efficacy than men using online learning and were more comfortable multitasking in an online course than men. As the age gap grew, self-efficacy also grew, showing that women participants later in age multi-tasked better and with more confidence in an online learning environment than their male counterparts. As stated in Chapter 1, VR is a rich multitasking and engaging learning environment. The findings of this study could inform future research to use VR as a model to determine interactions of self-efficacy on learning outcomes in multi-generational populations of differing genders. The results could inform better curriculum development with different delivery methods for students based on age and gender.

Summary and Conclusion

This study adds to the body of literature regarding learning outcomes using VR as a teaching and curriculum delivery tool. The final analysis used learning outcomes through test score comparisons, indicating that incorporating VR technology in live instruction has no different impact (positive or negative) from a traditional online classroom. The effectiveness of VR, like any other classroom experience, depends on the proficiency of the development of the curriculum and delivery methods unique to the students in the VR classroom. Lessons that are well-developed with clear learning objectives, active learning strategies, and opportunities for interaction and feedback promote student engagement and have the potential to increase learning outcomes (Freeman et al., 2014; Slavin, 2014).

Specifically, for non-traditional learners, Knowles's (1984) andragogy theoretical approach fits perfectly within a VR metaverse. One of the critical principles of andragogy is that adults are self-directed learners who want to take responsibility for their learning. Adults are motivated to learn when they see the concept's relevance to their own lives and when they can apply what they learned immediately to solve problems or meet needs. An immersive VR metaverse clears each of these principles with ease; an immersive environment allows for self-exploration, interactive learning, and the ability to apply learned knowledge immediately. This study's animal cell metaverse enhanced these principles, and the intentionally well-designed and developed curriculum using foundational research to guide its creation, also encouraged participants to be motivated members of their learning environment. Intentionally and thoughtfully developed and delivered curriculum integrated with a technology that enhances, involves, and expects interaction from participant interaction, allows non-traditional students the best opportunity to produce positive learning outcomes in a typically complex topic of instruction.

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Appendix A – Non-traditional Adult Learner Eligibility Survey

Do you identify as (Check all that apply):

- 25 years old or older?
- Currently attending college part- time?
- Currently working full time?
- A military veteran?
- A parent?
- Someone who waited at least one full year before entering a college academic program?
- Attained a GED?
- A first-generation college student?
- Having reentered a college program after leaving for more than year?

Appendix B – Demographic and Experience Survey

Section 3 of 3

Participant Information

The principal investigator seeks additional information from you. All questions are voluntary, and not answering a question will not preclude you from participating.

What is your age?

- ◯ 18 - 24
- ◯ 25 - 35
- ◯ 36 - 45
- ◯ 46 - 55
- ◯ 55+
- ◯ I chose to NOT answer this question

To which gender do you most identify?

- ◯ Female
- ◯ Male
- ◯ Transgendered Female
- ◯ Transgendered Male
- ◯ Gender non-conforming
- ◯ Not-listed
- ◯ I chose to NOT answer this question

What is your current degree program and level of education (associate, bachelor, graduate, post-graduate, other)?

- ◯ Associate
- ◯ Bachelor's
- ◯ Master's
- ◯ Terminal
- ◯ I chose to NOT answer this question

How many online college courses have you taken for credit?

- ◯ 1 - 1 5 courses
- ◯ 6 - 10 courses
- ◯ 10+ courses
- ◯ I chose to NOT answer this question

If you have taken online college courses, rate your general skill to navigate an online course using technology (circle one):

- ◯ 1–Not at all familiar
- ◯ 2– Slightly familiar
- ◯ 3– Somewhat familiar
- ◯ 4–Moderately familiar
- ◯ 5–Extremely familiar
- ◯ I have not taken any online college courses
- ◯ I chose to NOT answer this question

Have you ever used IVR, VR, or AR software or hardware?

- ◯ Yes
- ◯ No
- ◯ I chose to NOT answer this question

Do you regularly play video games?

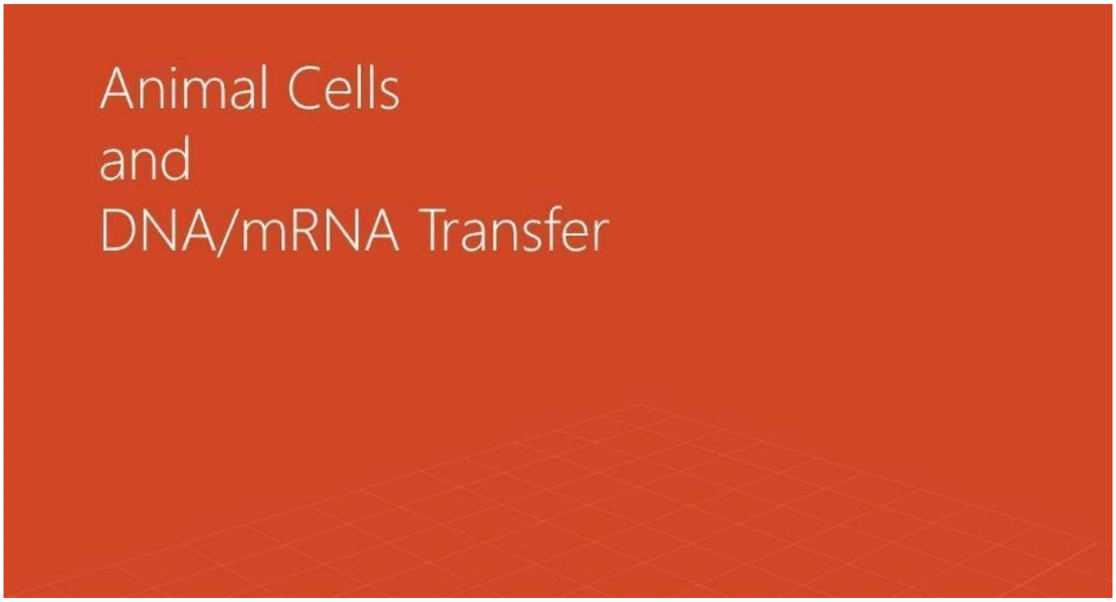
- ◯ Yes
- ◯ No
- ◯ Maybe
- ◯ I chose to NOT answer this question

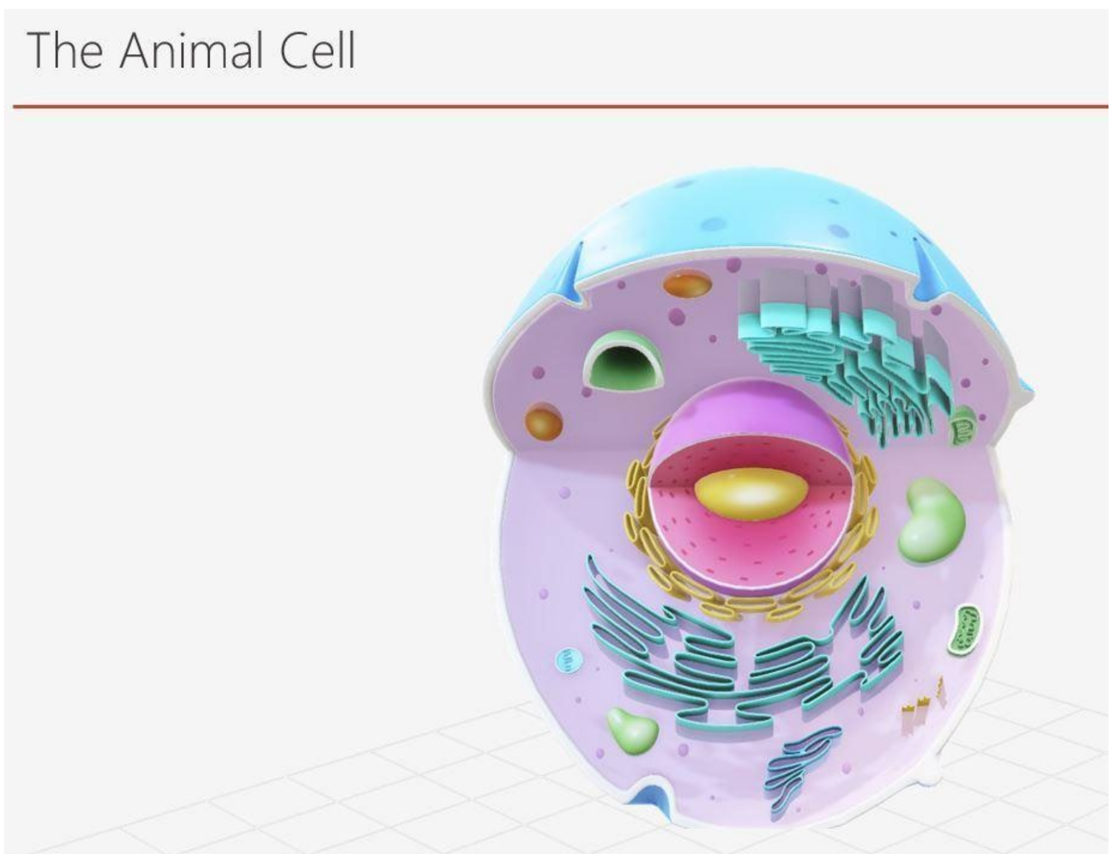
Appendix C – Pre/Post-Test Exam

1. The cell membrane is also called the:
    a. The organelle membrane
    b. The plasma membrane
    c. The lipid bilayer
    d. None of these answers
2. Cytoplasm is a ________ that fills the inside of the cell.
    a. gaseous substance
    b. small group of proteins
    c. watery substance
    d. jelly-like substance
3. Name two essential tasks the cytoplasm's cytoskeleton does:
    a. ____________________
    b. ____________________
4. What are the three things the cell membrane performs for the cell?
    a. ____________________
    b. ____________________
    c. ____________________
5. What are the small organelles composed of RNA-rich cytoplasmic granules that are sites of protein synthesis called?
6. What is the function of the mRNA in an animal cell?
7. What does "mRNA" stand for?

8. What happens when DNA is transcribed to mRNA (Transcription Stage)?
9. What happens when mRNA is translated to make proteins (Translation Stage)?
10. Why is the transcription and translation of mRNA important to the animal cell?

Appendix D – PowerPoint Lecture: The Animal Cell





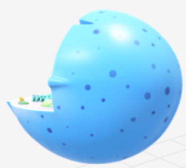
Learning Objectives

- ✓ To identify and understand the basic anatomy and many components of an animal cell, to include membrane, cytoplasm, organelles, and nucleus,
- ✓ To understand and explain how each of the components of an animal cell works together within the cell, and
- ✓ To identify the steps to create mRNA strands from DNA code to produce proteins that feed the animal cell.

Explain the main purpose is to understand the steps of creating mRNA strands from DNA code to produce proteins which feed animal cell
to feed the cell is to keep it alive. And to keep the cell alive is to keep our body's flourishing. DNA is the basic ID of humans. The mRNA helps to translate what the DNA is trying to do within our body (cells)
DNA = provider of details, mRNA is the translator to the rest of the animal cell through transcription.

Cell Membrane and Cytoplasm

- **Cell Membrane:**
  - Outer layer of cell
  - Called the **plasma membrane**
  - Provides a **boundary**, **protection**, and **delivery service** to the organelles inside
  - The membrane hosts a number of proteins, both within and on top of the lipid bilayer
- **Cytoplasm**
  - A **jelly-like liquid** that fills the inside of the cell
  - Composed of water, salts, proteins, and other organic molecules.
  - Exists inside of some organelles and other organelles are completely closed off from membrane
  - The structure of cytoplasm is highly organized, largely due to the **cytoskeleton** that helps **to scaffold the cell and give the cell its shape**



Cell membrane helps to protect all the organelles. It is the bouncer at the club–let's stuff in and allows things to leave–selectively–while protecting it's most precious cargo–all the stuff inside.
Cytoplasm: it gives shape to the cell and helps dissolve or remove waste. It allows everything to move around. If the Cell membrane is the is bouncer, the cytoplasm is the club owner making sure everything is moving around the way it should and taking out the trash when the trash needs taking out.

Organelles and Cytoplasm

- **Organelles:**
  - Mostly found in the cytoplasm
  - **The Nucleus is an organelle**
- **Nucleus**
  - Sphere that contains many organelles.
  - Controls many functions of the entire cell
    - Controls protein synthesis
    - **Contains DNA**
    - **Has a nuclear membrane**

Organelles–literally means "little organs". It's the inner workings of cell that make all the things work. If the Cell membrane is the bouncer and the cytoplasm is the club owner, the organelles are all the workers doing their job keeping the cell alive, working properly, and flowing.
The Nucleus is the brain of the cell. It carries DNA–which helps direct and tells all the things in the cell how to operate. If the Cell membrane is the bouncer and the cytoplasm is the club owner and the organelles are all the workers doing their job, the Nucleus is the Mob boss making sure her enterprise is working efficiently and professionally. It's the brain with all the info.

Ribosomes and rough Endoplasmic Reticulum

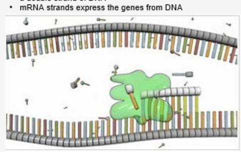
- **Ribosome**
  - Small organelles are composed of RNA-rich cytoplasmic granules that are sites of protein synthesis
  - Can be seen in Rough ER or in in cytoplasm
- **Rough Endoplasmic Reticulum**
  - Transport proteins
  - Continuous membrane system

Ribosomes: the cell's machinery. It carries the RNA to help match with specific proteins. If there ever was a wing woman at a club, Ribosomes are it. After matching the ribonucleic acid (RNA) to it's proper mate, it breaks up. It's work is done #friendzone

Rough ER: transports proteins to hook up with ribosome so the RNA can match up with the correct three letter codone.

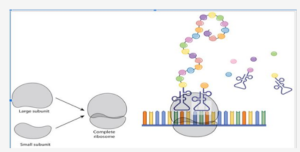
DNA to mRNA Transcription and Translation

- **mRNA**
  - **mRNA** means **M**essenger **R**ibo**n**ucleic **A**cid
  - Messenger RNA is a type of RNA that is necessary for protein production. In cells, mRNA uses the information in genes to create a blueprint for making proteins.
- **DNA mRNA __Transcription__**
  - Enzymes called RNA polymerases build single-strand RNA molecules from a double strand of DNA
  - mRNA strands express the genes from DNA



Clancy, S. & Brown, W. (2008) Translation: DNA to mRNA to Protein. *Nature Education* 1(1):101

- **DNA mRNA __Translation__**
  - After the DNA is expressed to a single strand of mRNA, Ribosomes read the single strand and create protein chains



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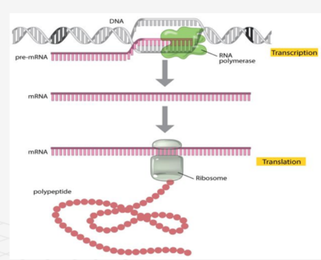
DNA to mRNA Transcription and Translation Conclusions

- **Conclusion**
  - DNA contains the code (blueprint) for the cell to continue to build proteins.
  - Amino acids, which are part of functional proteins, are what is translated when mRNA is transcribed into molecules from DNA.
  - **__Transcription__** and **__translation__** are important to an animal cell because it **replicates the proteins** needed for cells to be **healthy and alive**!



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