Understanding the Impact of Virtual Reality Upon Instruction of TCP/IP Subnetting

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Abstract

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Understanding the Impact of Virtual Reality Upon Instruction of TCP/IP Subnetting

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This mixed methods research study explores the university student learning experience of IP subnetting. Using a constructivist perspective, VR software was designed, written, and utilized in a learning process to gather both quantitative and qualitative data about the experience of learning IP subnetting. Participants underwent pre-test and post-test scoring to gather data about the depth of learning. NASA-TLX survey was implemented with all participants to gather quantitative data about situational learning factors. In addition, several participants were selected for interviews based on their scores.

Overall, the pre-test to post-test Change Scores revealed that both Control and Experimental groups had significant learning gains from the learning process. However, the Experimental NASA-TLX scores showed significantly less cognitive load and stress when compared to Control groups. Interview data details provided a rich description and a more detailed perspective regarding the NASA-TLX results. Overall results from the research process indicate that learning using a VR application for IP subnetting allows for more rapid creation of mental schema for the subject matter.

Dedication

Dedicated to my wife, Jennifer M. Bowie who taught me the most profound concepts I have ever learned. To my children, Hannah, John, and Kevin that keep me young and encourage an adventurous life.

Acknowledgments

I would like to thank Dr. Greg Kessler for all the help and support along the way, without him I'd be lost in the library or Wikipedia somewhere. He helped me formulate and codify the research here and was an unflagging supporter of this work.

Brandon Saunders is my co-worker, co-conspirator and most often supporter of my educational process and work. Without Brandon's help, support, and guidance my education and research would be much less than it is. A man I'm happy to call a friend.

Julio Arauz, my friend, co-worker, and current boss has never wavered in support of my education and its many twists and turns. His quiet confidence and guidance is always welcome.

I'm extremely thankful to Bruce Tong for his help and support in the creation of the VRIPS software. His detailed programming and system knowledge combined with his willingness to spend his time working with me to explain complex virtual programming concepts allowed me to complete the VRIPS software.

I am thankful to my committee members Drs. Greg Kessler, Gordon Brooks, Min Lun Wu, and Charles Linscott for all the advice, support, and feedback they have given throughout this process.

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Chapter 1: Introduction

"The most difficult thing is the decision to act, the rest is merely tenacity. The fears are paper tigers. You can do anything you decide to do. You can act to change and control your life; and the procedure, the process is its own reward." attributed to Amelia Earhart (Emma, 2019).

Overview

The education of undergraduate learners in the material of Transmission Control Protocol Internet Protocol (TCP/IP or IP) networking and subnetting has been at the core of my instructional duties for the past 15 years. Beginning as a master's student and struggling to learn the topics from a binary math-based perspective it became my mission to create instructional material that did not require binary math to express the underlying algorithmic process. My own game centered nature, cultivated throughout 40 years of playing both paper and pencil (PNP) games and computer video games, provided the background needed to create functional instructional material.

The method I designed became popular with students and faculty as adjunct learning alongside the traditional binary math method. Faculty colleagues call upon me as a guest lecturer to teach "my method" of IP subnetting nearly every semester at the undergraduate and graduate level. In 2006 the "Bowie Method of IP Subnetting" was created and eventually virtualized into YouTube learning segments (Bowie, 2020a, 2020b).

The materials and methods created were born from gut instinct and trial and error. Upon entering my PhD program, I took on the task of both extending my knowledge and perspective to assess why that instructional material worked and how to improve it. Many of the topics in TCP/IP Networking are completely abstract concepts. Concepts that are never seen, heard, or felt other than in response to another process. My task as an instructor is to explain the inner workings and logic of what goes on in this unseen. To explain technology, I turn to technology. The past several years have seen a blossoming of Virtual Reality (VR) technology (Nicas, 2016). Mixing a constructivist and pragmatic perspective, I intend to utilize VR technology as a conduit to convey deeper knowledge of learning IP Networking to undergraduate students.

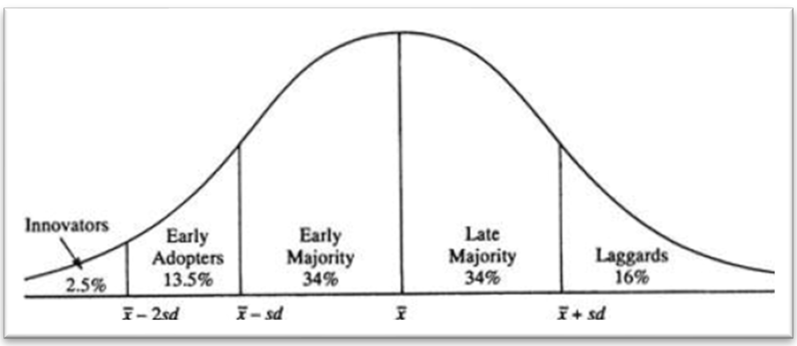
Virtual Reality is a new instrument in the educational field for a variety of reasons such as cost, complexity, lack of software and more. For this reason, little formal research has been done investigating its application in the classroom. A mixed methods research (MMR) design was chosen because it combines the strengths of each methodology during the study to provide not only a wider view, but also a deeper view on the issues of the phenomena being studied.

Rationale

Learners are continuing to find new ways to exchange ideas and knowledge often outside the traditional channels of communication. If the educational system is not actively engaged and participating in those new ways of communication and education, as they evolve, the system will continue to struggle to be relevant to learners that have moved on to learning styles and outlets of knowledge that meet the learner in the environment in which they currently learn. In short, the educational system will have to meet the learner where they are, not where the educational system defines the learner to be.

Figure 1

Adopter Categorization of the Basis of Innovativeness



Note. Figure 1 shows the rate of technology adoption (Y axis) across the life cycle of the product or service (X axis). Adapted from *Diffusion of Innovations, 5th Edition* (p. 371), by E. M. Rogers, 2003, Free Press. Copyright 2003 by Everett M. Rogers.

VR is an evolving product and communication space. New announcements are seen in the media outlets on nearly a daily basis about new content, devices, and human experiences via VR. As the technology adoption of VR reaches the apex of Roger's "*Adopter Categorization of the Basis of Innovativeness*" (E. M. Rogers, 2003, p. 357) curve, shown in Figure 1, showing lifecycle of realization of the "killer app" has or is being entrenched in the culture. Michael Lewis from MoneyCrashers.com defines the term killer app as a, "a computer application that saves money, time, or energy, makes the user safer, or enhances the experiences of the user to the degree that it must be acquired and used." (Lewis, 2020, para. 3). While the apex has not been reached yet momentum is growing daily as creators build new content and experience in the VR product space.

Previously the cost and complexity of VR devices kept them out of most classrooms and curriculum. Much in the same way that tablet computing was out of reach to most classrooms a decade ago. VR devices with high quality graphics and immersive content are now at the same price point as a mid-grade tablet computer (~$300). Educators need to leverage the immersive nature of VR environments for deeper learning of many topics, but most specifically topics that are by their very nature virtual or non-physical. The creation of VR content that can provide an immersive experience, both visually audibly, of a primarily virtual topic, supporting the scaffolding created needed deeper learner understanding.

To best understand the effectiveness of using VR to precipitate deeper learning of abstract concepts like TCP/IP subnetting facilitated in a blended learning environment it is needful to consider several different factors when considering a research design. To broaden understanding by including both qualitative and quantitative research a mixed methods research design allowed the alignment of a wide array of data needed to answer the research questions.

Traditionally, measuring learning outcomes has been done by ascribing numbers to specific students' aspects. Then using those numbers in an application of statistics to provide a generalized understanding of the population being measured. Classic test theory (CTT) is often presented as the first theory of measurement using a pre-test and post-test regiment (Lewis-Beck et al., 2004). The novelty factor introduced by VR equipment and environments requires more qualitative information from the participants to investigate where unanticipated learning blockades may have influenced the learning process.

Virtual Reality in an Educational Context

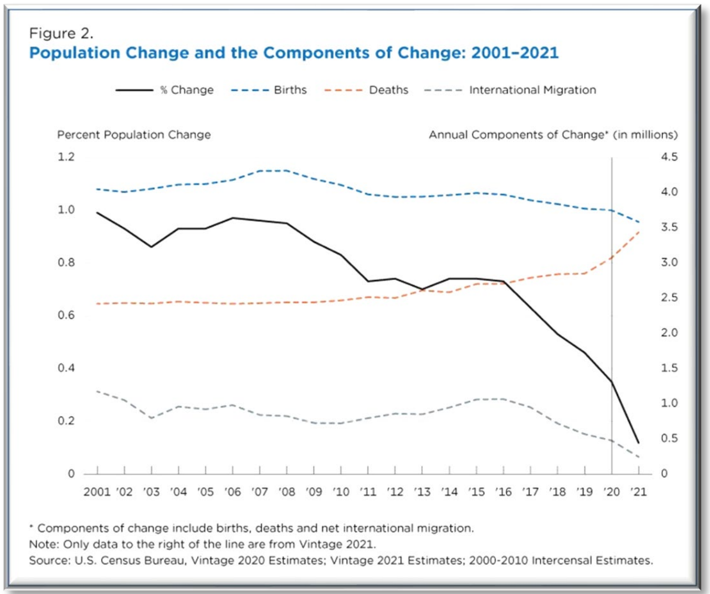
Regarding the current stage of computer-based media Mizuko Ito in 2007, "digital media are now commonplace and pervasive, having been taken up by a wide range of individuals and institutions in all walks of life." (Ito, 2008, p. 1). Ito also directly defines the current generations of students as, "a generation is growing up in an era where digital media are part of the taken-for-granted social and cultural fabric of learning, play, and social communication."(Ito, 2008, p. 1). Prensky, in 2001, labeled the generation of students that have grown up with and using digital technology as "Digital Natives" (Prensky, 2001, p. 1).

Innovative instructors continue to bring new technology into the classroom causing an upswing in adoption of classroom technology. Instructional Design researchers question the efficacy of the educational outcomes. However, the application of virtual environments in a learning context has been found to result in equivalent learning rates compared to real-world classroom settings (Georgieva-Tsaneva & Serbezova, 2020; Okutsu et al., 2013). Many schools and universities are being pushed both academically and financially to provide more online educational opportunities. The use of Virtual Reality (VR), Augmented Reality (AR) and XR (X is used as a variable placeholder for future technologies) provides an excellent opportunity to provide many of the benefits of traditional lecture interaction, on the job training and distance learning (Chen et al., 2017). As devices become more affordable and educational technology more pervasive it can be leveraged to transform the way instructional design is achieved (Dunleavy et al., 2009). Technology has and will continue to play an increasing role in education as it ties together a multifaceted landscape of students, technology and ideas (Prinsloo & Van Deventer, 2017).

In a February 21st, 2016 *Wall Street Journal* article Mark Zuckerberg predicted that the next popular platform for content delivery will be virtual reality (VR) (Nicas, 2016). A brief internet search returns a plethora of encouraging links suggesting that VR/AR/XR will assist K-16 and beyond learners. Such as Tanner Higgens's 2018 article, "*Five research-based ways to use VR for learning.*" (2018). Higgens expounds upon a variety of ways for the educator and student to utilize VR technology for educational gain. Examples include encouraging educators to focus on using VR to give student experience like field trips and guided learning experiences. Additionally, with older students VR can be used to provide an empathy building experience through showing a different potentially rarely seen point of view of a topic (Higgens).

Figure 2

Population Change and the Components of Change: 2001-2021



Note. Figure 2 shows population variance and components of change from 2001 to 2021. Data is from *Covid-19, Declining Birth Rates and International Migration Resulted in Historically Small Population Gains* (p. 2) by the U.S. Census Bureau, 2021 (https://www.census.gov/library/stories/2021/12/us-population-grew-in-2021-slowest-rate-since-founding-of-the-nation.html), by Luke Rogers. In the public domain.

Even before the 2020 COVID-19 pandemic the K-16 educational systems in the United States had begun to feel the pinch of a slower growth rate. The United States Census Bureau has been projecting a continued decline of the nation's growth rate as shown in Figure 2 (Rogers, 2021, p. 2) for many years. The trend affects not only the number of students being educated, but this also impacts tax revenue collected and distributed to schools. The lower available funds for schools at K-12 and Higher-Ed requires they become more efficient in the educational process. In more recent times hardware costs and other costs have lowered to the point that institutional regular use of VR/AR/XR technology as a teaching modality has become practical.

Transmission Control Protocol Internet Protocol Subnetting (TCP/IP Subnetting)

The definitional foundation for how the modern internet functions were laid out more than fifty years ago in 1969 when Steve Crocker, a then graduate student at UCLA, began a Request for Comment (RFC) series for a graduate project. The RFCs were an open communication with colleagues about the concepts and ideas in computer networking (Flanagan, 2019). As time passed the Defense Advanced Research Projects Agency (DARPA) project that became the basis for the modern internet grew. That growth spurred additional use of the RFCs as they shaped the communications and rules for the project (Flanagan, 2019). At the same time the RFCs became more formalized, becoming the definitive source for the system used by the internet today (Comer, 2014). Comer states, "Protocol specifications, such as those for TCP and IP, define the syntactic and semantic rules for communication." (Comer, 2014, p. 2).

The movement of data packets throughout networks is a fundamental part of communication used by people every day. Communication must be broken down and packetized, transmitted, routed, received and de-packetized and processed (Fall & Stevens, 2011). Another IETF RFC author and long-time Internet Engineering Taskforce (IETF) RFC editor Jon Postel wrote the following about the use of IP protocol in IETF RFC #791, "The function or purpose of Internet Protocol is to move datagrams through an interconnected set of networks." (Postel, 1981, sec. 2.3).

The need to understand how packets are routed through the network creates a need for people to understand the underlying systems. As Kozierok states, "Millions of people use TCP/IP and the Internet without really knowing how they work. For those in the technology field, however, understanding TCP/IP is becoming more important with each passing year.” (Kozierok, 2005, p. 39).

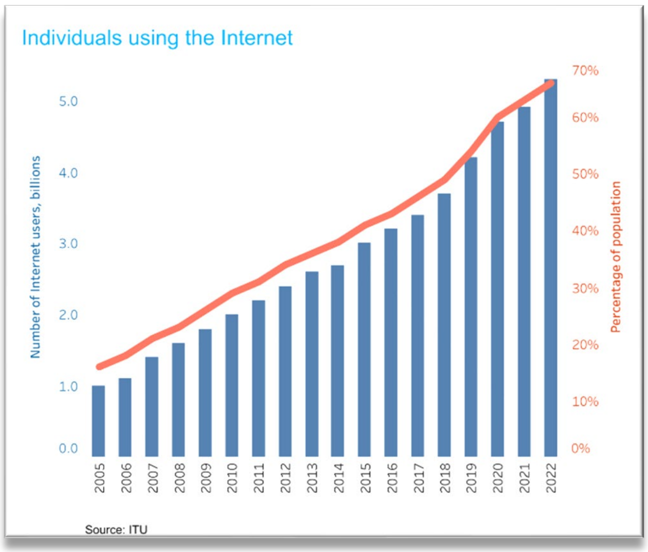
The number of devices connected to the internet is growing. Cisco Systems, a network hardware manufacturer and long-time industry watcher reports,

> The number of devices connected to IP networks will be more than three times the global population by 2023. There will be 3.6 networked devices per capita by 2023, up from 2.4 networked devices per capita in 2018. There will be 29.3 billion networked devices by 2023, up from 18.4 billion in 2018 (*Cisco Annual Internet Report - Cisco Annual Internet Report (2018–2023) White Paper*, n.d.).

The International Telecommunication Union statistics supports this view showing an significant increase in the adoption of internet users and devices as shown in Figure 3 (International Telecommunication Union - Statistics, 2023, p. 1).

Figure 3

Individuals Using the Internet

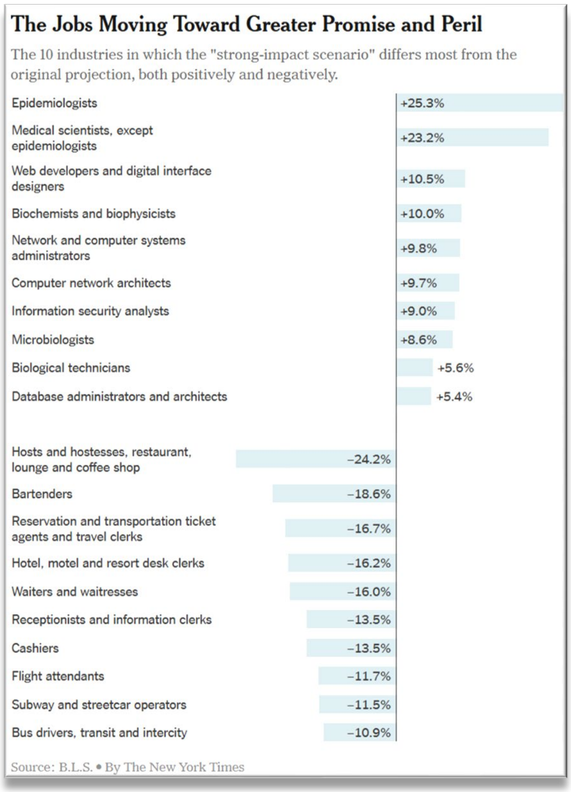


Note. Figure 3 shows the number of individuals using the internet from 2005 to 2022. Adapted from Development Statistics (para.1) by International Telecommunication Union International Telecommunication Union, 2023 (https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx). Copyright 2023 by International Telecommunication Union.

The continued growth means a larger demand in the workforce for competent and educated people to design and configure IP networks. New York Times reporter Jed Kolko presented late-2020 U.S. Bureau of Labor statistics projections indicating a 19.5% rise in employment in the combined industries “Network and computer systems administrators” and “Computer network architects” and more as shown in Figure 4 (Kolko, 2021, para. 7).

Figure 4

The Jobs Moving Toward Greater Promise and Peril



Note. Figure 4 showing industry job projections that differ from previous projections. Adapted from *The Jobs the Pandemic May Devastate* (para. 7), by J. Kolko, 2021 (https://www.nytimes.com/2021/02/22/upshot/jobs-future-pandemic-.html). Copyright 2021 by The New York Times.

Blended Learning Environments

Blended learning environment as a term and concept has evolved over time and throughout the literature. Earliest definitions referred to blended learning through the use of multi-modal avenues to present learning materials (Garrison & Vaughan, 2008; Hall, 2003; Muianga, 2005; Singh, 2003). The current definition typically used is a combination of traditional learning in-person learning environment combined with supplemental learning technology (Powell et al., 2015). Christensen et al. (2013) states that a blended learning program was a,

…a formal education program in which a student learns at least in part through online learning with some element of student control over time, place, path, and/or pace and at least in part at a supervised brick-and-mortar location away from home. The modalities along each student's learning path within a course or subject are connected to provide an integrated learning experience. (Christensen et al., 2013, p. 7).

This definition can be contrasted with a learning environment that is entirely online (e-learning) or completely conducted face-to-face (traditional learning style) (Yagci, 2016). Deperlioglu and Kose (2013) define a blended learning environment that includes face-to-face instructional delivery combined with technology e-learning for content delivery. The result is an attempt to provide deeper learning and engagement for learning for the learner by providing a more meaningful learning experience and improved educational process (Thorne, 2003).

Research Questions

An explanatory sequential mixed method research design was chosen to gain insight and knowledge using the following research questions:

RQ1: How do participants' scores change from pre-test to post-test?

RQ2: What are the effects of VRIPS software on participant cognitive load as measured by the NASA-TLX subjective workload assessment instrument?

RQ3: What insights do the qualitative findings provide to help us understand the nature of the experiment and its results?

Qualitative research methods are used to understand and explore specific, personal phenomena. While quantitative research methods investigate questions of generalizability to a larger population. Mixed methods research includes strengths from both methodologies through integration to provide a clearer understanding of the issues being investigated and provides a better understanding of the issues than through the use of one methodology alone (Creswell & Plano Clark, 2018).

The researcher selected an explanatory sequential MMR design to explore the efficacy of using VR as part of instructional design for the education of IP Network Subnetting. Creswell (2015) defines explanatory sequential design as having the intent to use a qualitative method(s) to help explain the quantitative result with more detail.

Virtual Reality is a new instrument in the educational field for a variety of reasons such as cost, complexity, lack of software and more. For this reason, little formal research has been done investigating its application in the classroom. Mixed methods research design was chosen because it leverages the strengths of each methodology during the investigation to provide not only a wider view, but also a deeper view on the issues of the phenomena being studied.

Significance of Study

This research was conducted with the specific goal of assisting students to learn more deeply about IP Networking and with a broader goal of understanding the issues and challenges surrounding the implementation of VR during the learning process. Previous research shows that Augmented Reality (AR) and Virtual Reality (VR) learning environments have a positive effect upon student learning objectives (AbdelAziz et al., 2020; Donalek et al., 2014; Jiménez-Hernández et al., 2020; Khan et al., 2019; Koper, 2014).

"Computer networking is often included as a subject in computer science, engineering, and business courses because computer networks are a fundamental component of information technology (IT) systems today" (Sarkar, 2008, p. 2).

The need for rapid adoption of technology is growing rapidly due to an increased reliance on technology. As seen during the pandemic, technology and its interconnected nature have become integral during daily life within both homes and businesses, creating a demand for personnel that have a deep rich understanding of both the technology and how it interconnects into the larger world network.

Target Audience

This study revolves around relevant issues that current educators are interested in Virtual Reality and its impact upon student learning outcomes. Technology is continuously and rapidly making changes upon the methods and modalities of both students and teachers. The research provides insight into how post-secondary aged learners might benefit from instruction scaffolded with virtual reality learning instruments.

Researcher Assumptions and Limitations

In any research study there are inherent assumptions and limitations from both external and internal to the researcher and participants. The list below is an attempt to acknowledge these limitations.

1. This study uses a quasi-experimental design and therefore results could be generalized to the entire population that samples were derived from.
2. Participants are asked to volunteer; however, interview participants are provided direct compensation in the form of gift cards.
3. Participants are all from a midsized, midwestern university that have self-selected a major program or coursework that involved computer networking.
4. Participants are assumed to have little to no knowledge of IP Networking issues and design considerations.
5. The VRIPS application is being actively developed and features present at the time of the study may be different than those at the time of publication.
6. Assumption that the NASA-TLX will provide valid data and be a reliable instrument to measure cognitive load.
7. Thematic interview data has some level of interpretation involved in the coding process. Though interrater reliability is used, it is conceivable that participants' correct meaning was not collected or interpreted correctly during those phases of the study.

Organization of Dissertation

This document is divided into five chapters. Chapter 1 is broken into multiple sections: the introduction, rationale, research questions, significance of the study, target audience, researcher assumptions and limitations. The final section provides the organizational overview of this document. Chapter 2 provides the literature review including definition of specific terms used thus imparting context for subject matter in relation to education, in addition the theoretical frameworks that are foundational to this work and the theories utilized to guide and construct the study are discussed. Chapter 3 presents a methodological overview of the study, including a detailed discussion of VR instrument creation, participant selection, data collection methods, study procedures, data analysis process, ethical perspective and protections of participants and coverage of potential validity considerations. Chapter 4 presents the study results including descriptive statistics for both pre/post-test and NASA-TLX survey data along with codes for the interview data. Chapter 5 provides the discussion results and findings along with any implications for applications in educational settings and discussions of future research. References and appendices are postpended at the end of the document.

Definition of Terms

Several unique and technical terms are used during this study. The following lexicon of terms is provided to expedite and simplify the understanding of this research study.

AR – Augmented Reality “allows virtual objects to be overlaid in real-world environments in real-time” (*What Is Augmented Reality - Technology, Examples & History*, 2022, para. 3). Additional detail is provided in sections below on this topic.

IP – Internet Protocol, see also TCP/IP.

NASA-TLX (NASA Task Load Index) – is a “subjective workload assessment tool which allows users to perform subjective workload assessments on operator(s) working with various human-machine interface systems.” (So, 2020, para. 1) It measures six mental stressors in two separate dimensions over a 20-point scale.

Network – Used in this context it refers to a collection of hosts that have IP addresses in the same subnet (Postel, 1981).

Subnet (noun) – A collection of addresses that are defined by a beginning IP address, called a network number and a subnet mask, which determines the network size, in terms of number of IP addresses (Postel, 1981).

Subnetting (verb) – The act of dividing a network into multiple (at least two) smaller networks, following the binary math rules required.

TCP/IP – "Transmission Control Protocol/Internet Protocol is a suite of communication protocols used to interconnect network devices on the internet." (Shacklett, 2021, para. 1). Defined in a series of RFC's starting in 1969, it has since grown to be used as the dominant network protocol worldwide.

Virtual – an approximation of the physical world rendered in a computer space. "simulating bits of our world (or completely imaginary worlds) using high-performance computers and sensory equipment" (Woodford, 2021, para. 1).

VR aka Virtual Reality - A virtual space may or may not have the perceptual fidelity or follow all the rules of the physical world. Additional detail is provided in sections below on this topic.

Virtual Reality IP Subnetting (VRIPS) – Virtual reality software package developed by the author of this study. Created in the Unity engine, implemented on the Oculus Quest platform to engage students in active learning of TCP/IP Networking concepts.

XR – eXtended Reality is "referring to the variable for any current or future technologies in spatial computing" (Alvirmin, 2021, para. 3). Additional detail is provided in sections below on this topic.

Chapter 2: Literature Review

"Not all those who wander are lost" (Tolkien, 1988, p. 198)

Purpose

This is a review of both the current marketplace and scholarly work, to better understand the context and relevant background research related to issues of creation and measuring effectiveness of instructional materials for Augmented Reality (AR), Mixed Reality (MR), Virtual Reality (VR) and Extended Reality (XR) in an education setting. While this research was implemented in a VR environment, the concepts used in the investigation fit into a larger economic and virtual landscape.

Figure 5

Concept Map of AR/MR/VR/XR Terms and Applications

Note. Figure 5 shows an XR concept map. Adapted from *What really is the difference between AR / MR / VR / XR?* (para. 2), by North of 41, 2018. (https://medium.com/@northof41/what-really-is-the-difference-between-ar-mr-vr-xr-35bed1da1a4e). Copyright 2018 by North of 41.

There is a wide application of terms in use both academically and professionally. A recent blog post from medium.com provides current taxonomy of terms and a visualization as shown in Figure 5 (North of 41, 2018, para. 2),

> VR is immersing people into a completely virtual environment; AR is creating an overlay of virtual content but can't interact with the environment; MR is a mixed [*sic*] of virtual reality and the reality, it creates virtual objects that can interact with the actual environment. XR brings all three Reality (AR, VR, MR) together under one term. (North of 41, 2018, para. 8).

For the remainder of this document, I use the more broadly applied term XR, however when in a specific situation I'll use the more specific term as needed.

For technology, such as XR, to have an impact on education, it must be accepted and adopted by that culture. Similarly, to other technologies that have reached this level of acceptance. For example, in 1983 Motorola sold the first commercial cellular phone. The handset price was $3,995 ($9,952 in 2020 dollars) (Federal Reserve Bank of Minneapolis, 2021), took ten hours to charge and provided only 30 minutes of talk time (Ha, 2010). Today cell phone companies have many competitors and hand sets are cheap in comparison, T-Mobile offers a $96 phone with the purchase of a cellular plan (T-Mobile, 2021), nearly 1000% price drop in 38 years.

The XR market currently finds itself in the early stages of this same type of evolution. The beginning of this document provides documentation of the current XR marketplace because the context is valuable not only in seeing how XR equipment is being used currently in an academic setting, but also to understand its role in larger society. Academic research investigating XR is only the start of the role XR technology could play in educational and everyday life in the future.

This review of XR in an educational context provides a comparison of viewpoints providing research from both supporters and detractors of XR material in pedagogical planning and instructional design, showing different perspectives on the state of this technology. Research done in the past decade is especially relevant in the context of this document as the rapid evolution of the technology and the high-quality experiences provided are significantly more immersive than previous work. XR research done earlier than ten years prior suffers from a technology gap that makes it difficult to compare with hardware and software available in today’s market. Earlier research, prior to ten years, was not bypassed however as it is extremely helpful providing a landscape in which sets current work. Providing a view not only of what has been investigated previously, but also how that research shaped, and continues to shape, research done today. It is my conviction that XR can and will bring deeper learning over a wider scope of topics than is currently available to learners of all ages.

Educational proponents of XR have had a positive outlook believing that it will benefit learners in an education context. However, in my opinion the *must have* application for XR is still being sought by developers, educators, and every other market sector. Current XR educational research reasonably justifies the additional time, expense and technology learning curve needed to bring XR into the mainstream classroom by balancing that against the potential learning outcome gains for students.

In a February 21st, 2016 *Wall Street Journal* article Mark Zuckerberg predicted that the next popular platform for content delivery will be virtual reality (Nicas, 2016). A brief internet search returns a plethora of encouraging links suggesting that XR learning will assist K-16 levels and beyond. Such as Tanner Higgens's 2018 article, *Five Research-based Ways to use VR for Learning* (2018). In it he expounds upon a variety of ways for educators and students to utilize VR technology for significant educational gains. Examples include encouraging educators to focus on using XR to provide student experiences such as field trips and guided learning experiences. When used with older students XR can be used to provide an empathy building experience by revealing a different, potentially rarely seen, point of view. (Higgens, 2018).

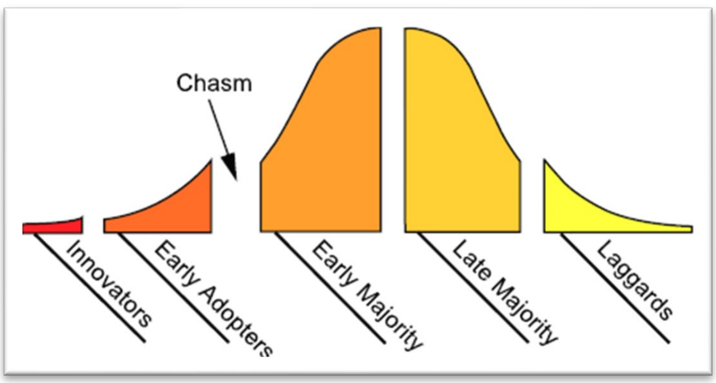
XR Adoption

During the introduction the concept of a "killer app" was discussed as part of the rationale for this study. Defined by Microsoft (Microsoft Press, 2002) as, "An application of such popularity and widespread standardization that it fuels sales of the hardware platform or operating system for which it was written." or "application that supplants its competition." (Microsoft Press, 2002, p. 499). Examples of some of the first apps recognized as "killer apps" are programs like WordStar, the first WYSIWYG (What You See Is What You Get) word processor or Mosaic, one of the first widely accepted web browsers (Lewis, 2020).

XR technology has only begun to transition from, "Early Adopters" to "Early Majority" (E. M. Rogers, 2003, pp. 359–360) and therefore the killer app for XR has really yet to settle upon the culture of users. The meaning of this is that while technology advocates believe that there is a killer application it either has not been found or has not been conveyed in a method that the larger culture can accept. Meade and Rabelo's (2004, p. 668) work defines the "chasm" between the Early Adopters and Early Majority as shown in Figure 6.

Figure 6

Technology Adoption Lifecycle



Note. Figure 6 shows the rate of technology adoption (Y axis) across the life cycle of the product or service (X axis). Adapted from "The Technology Adoption Life Cycle Attractor: Understanding the Dynamics of High-Tech Markets" by P. Meade and L. Rabelo, 2004, *Technological Forecasting and Social Change*, Vol. 71, Issue 7, p. 668 (https://doi.org/10.1016/j.techfore.2004.01.008). Copyright 2004 by Elsevier.

Into this chasm many products fall making it difficult to model mathematically or graphically determine where exactly a product lies on this continuum (Meade & Rabelo, 2004). In Geoffrey Moore's book, *Crossing the Chasm* (2014), he uses an recent example product, the Apple iPad stating,

> in boardrooms across America the iPad had become a socially acceptable way to be always online, in part because one could distribute board materials to it

> electronically to be accessed during the meeting. Then the kids got their hands on them, and there was a massive explosion in use cases, primarily Facebook and other forms of social computing, but also including leveraging the World Wide Web for broader educational impact. (Moore, 2014, pp. 19–20)

Some technology advocates believed that 2020 was the year when VR leaps the chasm. In Ben Hoyt's 2020 article, *Half-Life: Alyx and the Rebirth of Consumer VR,* felt that the market stumbled post 2014 and nearly fell into the chasm (Hoyt, n.d.). He stated, "Unfortunately, large corporations (Samsung and Google, in particular) realized that their existing smartphone devices could be shoe-horned into cheap plastic (or cardboard) shells with lenses in order to deliver experiences that could be described as 'VR.'" (Hoyt, n.d., para. 5).

Hoyt's article continues, stating that only now is the hardware becoming cheap enough and untethered enough from a local PC enough to come into its own as a product. Hoyt believes that titles such as *Half-Life: Alyx will show the potential of XR as a killer app for entertainment* (Hoyt, n.d.).

Industry and media have also been probing the edge of VR as a training technology. Charlie Fink's 2019 Forbes article titled, *Is Training VR's Killer App? Ask Forklift Drivers* explored the fledgling product space of VR based industrial training. After experiencing the FreeRangeXR training software Fink states he was, "blown away" by the experience and that, "Training and simulation of this kind are turning out to be the killer app for VR, and its use is expanding." (Fink, 2019, para. 4).

Raymond Corporation, a subsidiary of Toyota began development in 2016 of FreeRangeXR in response to a need for expertly trained material handling operators. Any new technology is a learning experience. New software that performs similar tasks, like photo editing, requires the user to work through a new learning curve. That new functionality is called an affordance (Gibson, 2014). An affordance may be obvious like a ladder that provides access to the roof. Or they may be less obvious, such as using the ladder to cross a gap between two buildings. In many ways XR can provide users with a familiar experience, such as video chat. More importantly XR also has the possibility for new affordances: immersive real-time 3D conferencing. Currently, XR users, researchers and educators are still figuring out the hardware and pushing at the edges of what is possible. Recent research is starting to lay out some of the possibilities and map the basic use case footprint for XR technology.

XR Context and Definitions

To fully understand the background and spectrum of devices and modalities the following XR context and definitions are detailed. In 1994, Milgram and Kishino (1994) provided one of the most documented examples of a continuum that contains XR called the: “Simplified representation of a ‘virtuality continuum’”, shown in Figure 7 (Milgram & Kishino, 1994, p. 3).

Figure 7

Simplified Representation of a 'Virtuality Continuum'

Note. Figure 7 shows the Virtuality Continuum. Adapted from "A taxonomy of mixed reality visual displays" by P. Milgram and F. Kishino, 1994, *IEICE Trans. Information Systems, Vol. E77-D, No. 12.*, p. 1324 (https://www.researchgate.net/publication/231514051_A_Taxonomy_of_Mixed_Reality_Visual_Displays). Copyright 1994 by Paul Milgram and Fumio Kishino.

In their work they provided not only an XR continuum to provide context, but also the language, through existing hardware/software examples, needed to help define it. Milgram and Kishino (1994) defined six classes of mixed reality computing interfaces. They defined these classes of experiences from the left side of the continuum and moving to the right, each step a deepening of the virtual immersive context (Milgram & Kishino, 1994, p. 3). The class definitions shown below are Milgram and Kishinos. I provided, explanation, examples, and product references to each of the classes based on information or products available in today's market:

- "1. Monitor Based (non-immersive) video displays" (Milgram & Kishino, 1994, p. 3) – The typical monitor keyboard setup in use today.
- "2. Video displays" (Milgram & Kishino, 1994, p. 3) – Very similar to monitor based but using head-mounted displays (HMDs). Very few examples of this technology are in production.

- "3. HMD's with limited opacity onto real-world scenes" (Milgram & Kishino, 1994, p. 3)– Allowing virtual objects to be superimposed onto reality. Microsoft Hololense and Google Glasses are examples of this technology (Google, 2021; Microsoft, 2021). Pokémon Go on a smartphone is a lower end hardware example (*Pokémon GO*, n.d.).
- 4. Very similar to Class 3 however the "real" world is brought into the HMD using live streamed video. The Oculus Quest 1 and 2 perform this as a passthrough function (Meta & Oculus, 2021) allowing users to be fully immersive and a degree of MR. (Milgram & Kishino, 1994)
- "5. Completely graphic environments" (Milgram & Kishino, 1994, p. 3) – A fully computer-generated environment with no "real world" elements. This is the current level of technology generally available on the market today. Oculus Quest 1 and 2, Valve Index VR Kit and HTC Vive Pro 2 are among the most popular currently (Greenwald, 2021).
- "6. Completely graphic but partially immersive environments" (Milgram & Kishino, 1994, p. 3) – At this level real world objects are represented virtually and can be interacted with. In addition, haptic feedback equipment could be utilized to provide virtual environment feedback to the user. Several companies have created products in this embryonic product space. bHaptics and Woojer each offer a haptic vests that can provide sensory feedback to the user in the form of vibration feedback points used to simulate different types of touch or deep bass feeling of sound (KnoxLabs.com, 2021; Woojer, 2021). On December 28th, 2021 bHaptic

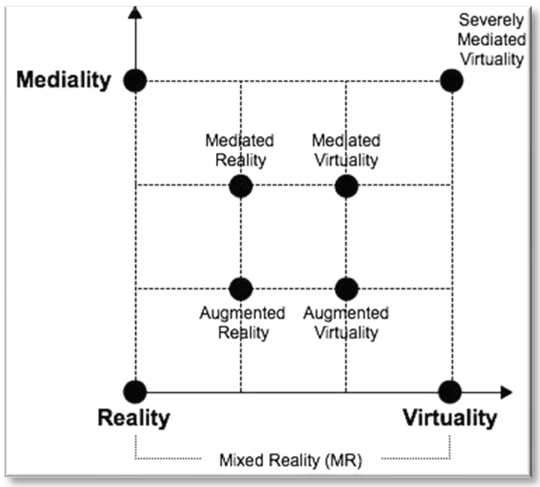
announced the Q4 2022 release of *TactGlove VR Haptic Glove* for XR systems (bHaptics.com, 2021; Sprigg, 2021). Meta (previously Facebook), creators of Oculus Quest hardware, have also teased that they may be entering the haptic glove market (Meta, 2021). This is a rapidly expanding space and there is still a large need for user assessment in the marketplace space at this level.

As detailed above, several classes have existing use cases and products serving or are attempting to serve that role. While in other cases, such as class two HDM monitors, a user need never manifested therefore a product was not created or repurposed.

Steven Mann (1994) defines a broader framework of virtual space. They believed that Augmented Reality, as defined by Milgram and Kishino, did not specifically include the possibility of using or reusing physical elements in the virtual world. They proposed a larger scoped general framework that included the mixing of virtual and physical elements. Their Mediated Reality Framework, shown in Figure 8 (Peña-Rios, 2016, p. 20). provide a function of mixing virtual and physical elements beyond the scope of Milgram and Kishino's continuum.

Figure 8

Mann's Mediated Reality Framework



Note. Figure 8 shows an updated reality framework. Adapted from "Exploring Mixed Reality in Distributed Collaborative Learning Environments," by A. Peña-Rios, 2016, Peña-Rios, (p. 3), (https://www.researchgate.net/publication/318217122_Exploring_Mixed_Reality_in_Distributed_Collaborative_Learning_Environments). Copyright 2016 by Anasol Peña-Rios.

Mann believed that technology could be used as a reality mediator to in part diminish reality (Mann & Fung, 2001). As Mann states,

> Diminished reality is as important as Augmented reality, and both are possible with a new device called a Reality Mediator. A Reality Mediator allows the wearer's visual perception of reality to be altered in such a way that the user can delete or diminish undesirable visual detritus from their perceived environment (Mann & Fung, 2001, p. 1).

Figure 9

Diminished Reality

Note. Figure 9 demonstrates diminished reality. Adapted from "Video Orbits on Eye Tap Devices for Deliberately Diminished Reality or Altering the Visual Perception of Rigid Planar Patches of a Real World Scene," by S. Mann and J. Fung, 2001, *Proceedings of the International Symposium on Mixed Reality (ISMR '01)*, p. 8 (https://scholar.google.com/citations?view_op=view_citation&hl=fr&user=7bmQ4FgAAAAJ&cstart=300&pagesize=100&sortby=pubdate&alert_preview_top_rm=2&citation_for_view=7bmQ4FgAAAAJ:WbkHhVStYXYC). Copyright 2001 by Steve Mann and James Fung.

The addition and subtraction of visual, audio, and tactile elements in a virtual context are a combination of Milgram classes and Mann's concepts of reality mediation. Together they provide the common definition of augmented reality in use today as shown in Figure 9.

In the same year that Milgam & Kishino, and Mann & Fung were defining the physical and sensory continuum and framework of XR, Michael Hiem (1994) released, *The Metaphysics of Virtual Reality.* Inside Heim provides seven qualities that he believed were an essential part of a virtual experience. He defines some of the earliest qualitative aspects for virtual environments. There is overlap with Milgram and Mann's concepts at several points however several elements are unique:

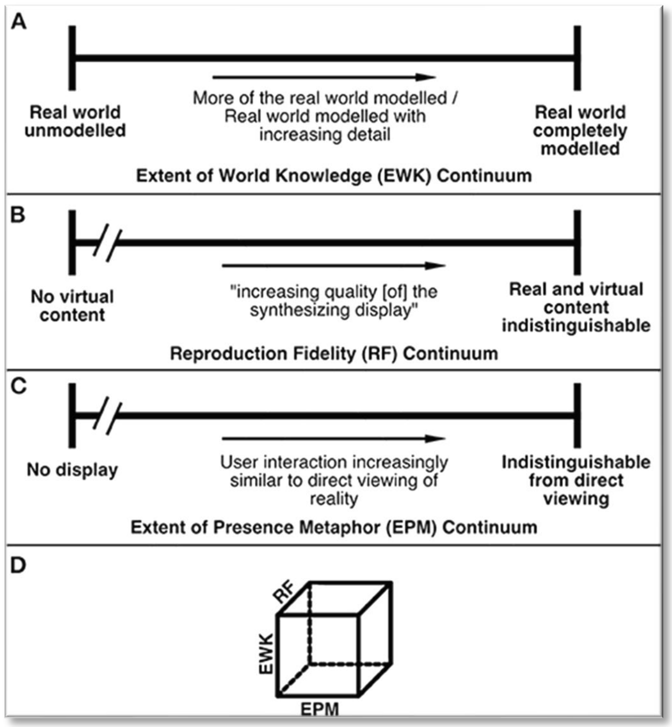
- Simulation – Generation of virtual objects and locations in high definition
- Interaction – Contact or communication with objects within the simulated environment.
- Artificiality – World creation and interaction that is not a representation of the physical world. A world that is largely a human construction.
- Immersion – A user mental state in which physical awareness is lessened by the virtual environment. Several researchers believe that this is synonymous with a flow state (Michailidis et al., 2018).
- Tele-presence – The sense of self (aka presence) inside the virtual environment. Recent studies (Christopoulos et al., 2018; Makransky et al., 2019) indicate that high definition of graphics affects the perception of realism and leads to the sense of presence within the virtual environment. The sense of presence has been correlated with deeper learning and positive learning outcomes.
- Full-Body immersion – Through the use of technology the ability to experience the virtual world in a physical way, not being limited to sight and sound.
- Network Communication – Connectivity to others to enable sharing of information, objects, and experiences in a virtual environment.

More recently other researchers have proposed updating the Milgram and Kishino's (1994) virtuality-continuum to include only a broader spectrum of experience types and a wider depth of physical world interaction. Skarbez, Smith and Whitton's

(Skarbez et al., 2021) work examining Milgram and Kinshono’s virtuality-continuum and extending it to creating a taxonomy, “in order to be able use it to categorize not only mixed reality technologies, but also, and importantly, mixed reality experiences” (Skarbez et al., 2021, p. 5). Shown below in Figure 10 is a 3-dimensional taxonomy consisting of Extent of World Knowledge (EWK), Reproduction Fidelity (RF) and Extent of Presence Metaphor (EPM).

Figure 10

Three-Dimensional Taxonomy Consisting of EWK (A), IM (B), and CO (C) Dimensions, as Well as the Relationship Among the Three (D)



Note. Figure 10 shows the multidimensional relationships of World Knowledge, Reproduction Fidelity and Presence Metaphor. "Revisiting milgram and kishino's reality-virtuality continuum," by R. Skarbez, M. Smith and M. Whitton, 2021, *Frontiers in Virtual Reality, Vol. 2*, p. 6 (https://doi.org/10.3389/frvir.2021.647997). Copyright 2021 by Skarbez, Smith and Whitton.

The additional continuums discussed originated in Milgram and Kinshono's 1994 paper. Skarbez et al. extend that and have provided the intersectionality in 3-dimensions providing a more comprehensive context for experiences to be gauged upon.

Taxonomies provide language to define, describe and organize concepts and relationships (Depoy & Gitlin, 2015) and are necessary to create common language for research and understanding. However, the application of language to a concept can define, guide and restrict meaning of an idea (Boroditsky, 2018). Recent philosophical research brings additional depth to the discussion of virtual reality, virtual environments, and experiences gained in both physical and virtual contexts. David Chalmers (2022) book *Reality+: Virtual Worlds and the Problems of Philosophy* contends that that Milgram's continuum is poorly named stating that, "because it bakes in the premise that virtuality is opposed to reality" (Chalmers, 2022, p. 257). Chalmers continues with, "A better name would be the *physicality-virtuality* continuum. Standard VR systems are largely pure virtuality, while AR systems augment physicality with virtuality." (Chalmers, 2022, p. 257).

Chalmers' persistent claim is that even though virtual objects may only exist in a specific perspective, in a computer system, the effect and experiences the object has on the human is real. Even though the object was created and exists in one perspective, its very existence and effects of that existence apply into multiple perspectives and realities.

A good example is that of this document. In one context it is a collection of bits on a digital storage device, in one of several formats (PDF, MS-Word, etc.) in another it is printed ink on paper. My position is that ultimately the perspective representation of the object is not the important issue. The knowledge it can provide and the effect that knowledge can have on the human experience makes the object real in all contexts in which it exists. Knowledge learned in a virtual experience becomes part of the learner's lived experience and can be applied in multiple realities.

Virtual reality learning environments provide opportunities that have not existed in the past, giving new options to view and interact with objects and concepts in such a way that allows for deeper learning (Ikhsan et al., 2020; Kartiko et al., 2010). Additionally, those virtual learning environments access learning methods that are unavailable in physical reality. This is not to say that all learning is best done in a virtual context. The application of new learning methods like virtual reality needs to be explored such that they can be applied in the correct context for deeper or less stressful learning.

Neuroplasticity and Virtual Reality

Current research in neuropsychology indicates that the human brain can rewire itself as new neural pathways are both needed and exercised (Doidge, 2007, p. 63). Neuroplasticity is defined by Kendra Cherry (2022) as, “a term that refers to the brain's ability to change and adapt as a result of experience” (Cherry & Lakhan, 2022, para. 1). Doidge’s 2007 book, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science* (2007, p. 69) reports upon research by Merzeich and Jenkins in the 1980’s finding that as neurons in the brain are trained they become more efficient and faster. More recent research correlates neuroplasticity and virtual reality with positive results in several different contexts (Cheung et al., 2014; Coco-Martin et al., 2020, p.; Hao et al., 2022). Virtual reality’s ability to provide new experiences and/or to work with existing concepts in a context that is a less consequence enabled environment. Which can allow users to build neural pathways in VR that transfer to tasks in the physical world.

Immersive Learning Within Virtual Learning Environments

Technology adoption in education has raced ahead of faculties' ability to utilize it effectively and that rate is predicted to rise (McCormack, 2021). While currently the primary modality of these tools is visually and auditory based the immersive nature of XR experiences creates exciting new learning opportunities. Immersive learning (IL) and virtual learning environments (VLE) are a combination of in-person knowledge transfer blended with a plethora of immersive technologies options. They can support participatory group-based learning, distance, in-person and hybrid experiences (Facebook et al., 2021; Spatial, 2021). Or it can support self-paced, learner directed experiences providing instructor support, flexible assessment, and scalability.

The continuums and frameworks provided above provide a characterization of immersion. Most often apply is aspect of spatial immersion or “presence”, provided when a user has the, “feeling like you are actually ‘there’” (Barfield et al., 1995, p. 473). The perception of presence is a prime element that provides constructivist learning methods (i.e., problem-based learning, experimental based learning, exploratory learning) the opportunity to be applied in an immersive learning context.

How technology is applied in immersive education and its’ function within the learning activity was codified by Schrader (2008):

- Learning ABOUT technology – Learning technology skills or important details of technology, the learning “of corresponding cognitive and affective variables associated with technology” (Schrader, 2008, p. 462), for example learning HTML for web page creation and design.

- Learning FROM technology – Technology is assuming the role of instructor, “technology is the medium of instruction, whether it is mathematics or technology, and not merely the content” (Schrader, 2008, p. 463), for example self-paced online e-learning instruction.
- Learning WITH technology - Technology partnership with the learner that relieves the learner’s working memory and cognitive function free, allowing cognitive attention paid to higher-complexity tasks, “As a result of these partnerships, humans can engage with content, think, and achieve goals that were otherwise impossible individually” (Schrader, 2008, p. 464), for example using a spreadsheet application.
- Learning WITHIN technology - Technology is the underlying substrate for the education process, “users function, learn, and interact within the technology” (Schrader, 2008, p. 466), for example immersive virtual worlds like Second Life’s University offerings (Second Life, 2021) or XR simulation training in a variety of industries (FreeRangeXR, n.d.).

Designing XR Enriched Instructional Material

It is difficult to imagine learning occurring in a medium completely devoid of technology. As Smart Sparrow (n.d.) said, “in today’s screen-centered world, learning has become a more complex collaboration between the instructor, the learner, and the medium” (Smart Sparrow, n.d., para. 6).

Thoughtful consideration should be taken before endeavoring to create technology centered instructional material. Koper et al. (2001) defeines learning design as, “a description of a sequence of learning activities that learners undertake to attain some learning objectives, including the resources and support mechanisms required to help learners to complete these activities “ (Koper & Miao, 2009, p. 41).

XR instructional material often embodies a constructivist learning perspective through the applications of varying levels of presence in the learning environment (Selzer et al., 2019). Instructional designers should consider how the technology affects factors such as student-centered learning, the execution of realistic tasks, encouragement of ownership, collaboration, social interaction, the use of multiple modes of representation, and awareness of the knowledge construction (McLeod, 2019a). van Eijl and Pilot (2003) shared their experiences designing online engaging course work stating, “Designing proved to be a learning process.” And that “most examples of good practice had been developed as a result of trials” (van Eijl & Pilot, 2003, p. 55). They considered several factors crucial to success in course design: VLE learner introduction and education at the course start to ease frustration, blend both live and virtual instruction to increase student and group communication, utilize collaborative features of the technology platform to promote student involvement, allow students to leverage internet resources from within the platform to increase subject matter authenticity (van Eijl & Pilot, 2003).

Wegener and Leimeister’s (2021) research on Virtual Learning Communities (VLC) added to this understanding. Their research indicates several necessary factors needed for success: “a strong, present and helpful instructor that acts in different facilitation roles, face-to-face meetings that help to establish social ties, and small-group assignments that offer concrete goals and avoid information overload." (Wegener & Leimeister, 2021, p. 384).

XR's Application in Education

To highlight current issues in the educational adoption of XR this section is laid out in point/counter point style for easier comparison. Reading the literature about XR adoption in education several themes presented themselves.

Opposing View Argument

Student Privacy Issues. Educational detractors of XR often have two reasonable issues, student privacy and economics. In Craig and Georgieva 2018 Educause Review article, *VR and AR: The Ethical Challenges Ahead,* they outline several of the potential pitfalls that need to be addressed as this technology becomes more mainstream. One issue they called attention to pointed to the addition of any type of social media functions that could create opportunities for potential cyberbullying. Currently many XR applications offering multi-user and/or public social connection functionality also have controls to allow for users to isolate themselves. This does not solve the basic harassment environment issue or deal with the instigator of the behavior; it is seen as a short-term control for the issue (Craig & Georgieva, 2018). The National Education Policy Center (NEPC) published, *Personalized Learning and the Digital Privatization of Curriculum and Teaching* by Boninger, Molnar and Saldaña in 2019 that explored and reported on student and teacher data privacy and corporate financial interests in the student and instructor data. In their report they made several recommendations for safeguarding student and teacher data including,

- "Requires the entity collecting data to disclose its financial interests and business relationships as well as any potential commercial implications of data collection" (Boninger et al., 2019)
- "Vests the ownership of any and all data collected on a student with the student or the adult(s) legally responsible for the student" (Boninger et al., 2019)

These types of issues are normally dealt with in an software End User License Agreement (EULA) and as part of Family Educational Rights and Privacy Act (FERPA) (*Family Educational Rights and Privacy Act (Ferpa)*, 1971). However, users often do not take EULAs seriously. An Association for Computer Machinery study by Böhme and Köpsell in 2010 noted, "More than 50% of the users take less than 8 seconds, which is clearly too short to read the entire notice." (Böhme & Köpsell, 2010, p. 2405).

Even early adopters of the VR gear like Facebook's new Oculus Quest 2 have reservations about the privacy implications as voiced by Emory Craig a VR technologist and reviewer commented in 2020 about large corporations' data security policies and history,

> their [Meta, previously Facebook] overall track record on privacy is a far more serious issue. I don't want to hear of another Cambridge Analytica crisis where the data this time includes my physical movements and speech inside my own home (Craig, 2020, para. 19).

Economic Costs of XR. Economic cost of the equipment is often a point of concern for both parents and school districts While some educators are enthusiastic about using XR in the classroom others are less enthusiastic stating, "VR headsets sound amazing in reality they will be just another nifty tech gadget, if you can afford it. Certainly not something you'll be seeing in schools." (Wilson, 2016, para. 18).

As recently as two years ago VR headsets like the HTC Vive $1662 (Amazon Inc., n.d.) and Oculus Rift $798 (Matney, 2017) required being tethered by cable to a parent device. An additional purchase of a high powered, high-priced gaming PC costing around $1500-$2000 USD (Dell, n.d.; Vive, 2020) was also required. While tethered VR visors allow access to the PC's high-powered video processing card which, while it creates an amazing user experience, is difficult for most people and educational institutions to justify the additional cost and dedicated space needed.

Supporting View Argument

Student Privacy Issues. Technology is as rapidly moving and evolving as the humans that create it. As such governmental law and policy will chase technology forever. Since before the beginning of the internet and its subsequent corporatization user privacy and data security have been issues. The United States many laws and policies have been enacted to attempt to protect the data privacy of its citizens. For example, Health Insurance Portability and Accountability Act of 1996 is a, "federal law that required the creation of national standards to protect sensitive patient health information from being disclosed without the patient's consent or knowledge" (*Health Insurance Portability and Accountability Act of 1996 (Hipaa)*, 2019, para. 1).

There are several clauses that specifically call out protections when utilizing technology. Health providers are required to abide by the, "Privacy Rule, which is all individually identifiable health information a covered entity creates, receives, maintains or transmits in electronic form" (Rights (OCR), 2009, para. 11).

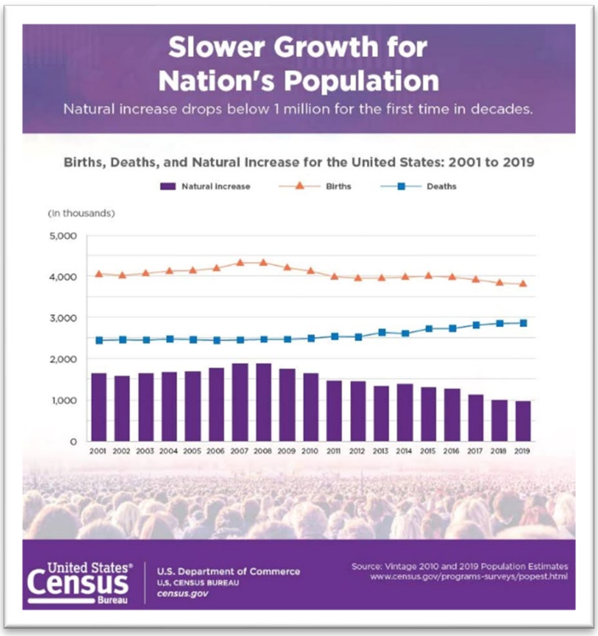
Medical records systems existed, on paper and electronically, before this type of regulation came into effect. It took time to create legislation via the United States legal system. As technology continues to create new environments and situations the legal realities need to be explored and the safety and privacy of individuals and corporate entities need to be protected.

Specifically related to schools and student privacy a pre-internet age policy, FERPA (*Family Educational Rights and Privacy Act (Ferpa)*, 1971), in the United States is used to provide overarching, but not technology specific privacy and protections. FERPA has had major provisions added by Congress nine times, the most recent in 2011, to clarify and codify the provisions of the law. Many of those changes were a direct result of changes in our culture and society (Center, n.d.). As a society and culture, we need to use legislative policies and laws to create a new paradigm that matches our current use of technology. Such a piece of legislation is not perfect and cannot make all users happy. Until such time that a clearer understanding of how and when XR technology is being used in both the classroom and non-classroom settings caution needs to be used in its application and continued thoughtful research conducted to understand XR function in the learning process.

Economic Costs of XR. Before the start of the 2020 COVID pandemic, K-16 educational systems in the United States had begun to feel the pinch of a slower population growth rate. Sandra Johnson of the United States Census Bureau has been projecting a continued decline of the nation's population growth rate, shown in Figure 10 (Johnson, 2019, para. 14), for many years.

Figure 11

U.S. Growth Projection 2019



Note. Figure 10 projects slower US population growth. Adapted from New Estimates Show U.S. Population Growth Continues to Slow, 2019 (https://www.census.gov/library/stories/2019/12/new-estimates-show-us-population-growth-continues-to-slow.html). In the public domain.

This precipitous trend affects not only the number of students that need an education, but also tax revenue being generated and allocated to school districts and institutions. Meaning that schools, both K-12 and higher-education must become more efficient at educating students and need to be aware of the economic costs involved. Only recently have the hardware costs and underlying space cost come down to the point that regular use of XR technology in an educational role has become practical.

Until very recently VR required the use of a tethered headset connected to a powerful, and expensive PC. However in 2018, Oculus introduced the Oculus Go $299 (Oculus, 2020a) based on a Google smartphone chassis. The device was cheap and operated without a cable to tether it to any kind of PC. Only months later, Oculus introduced a more powerful version, the Oculus Quest $299 (Oculus, 2020d), which provided a much higher quality video environment while still not requiring to be tethered to a PC for video capability.

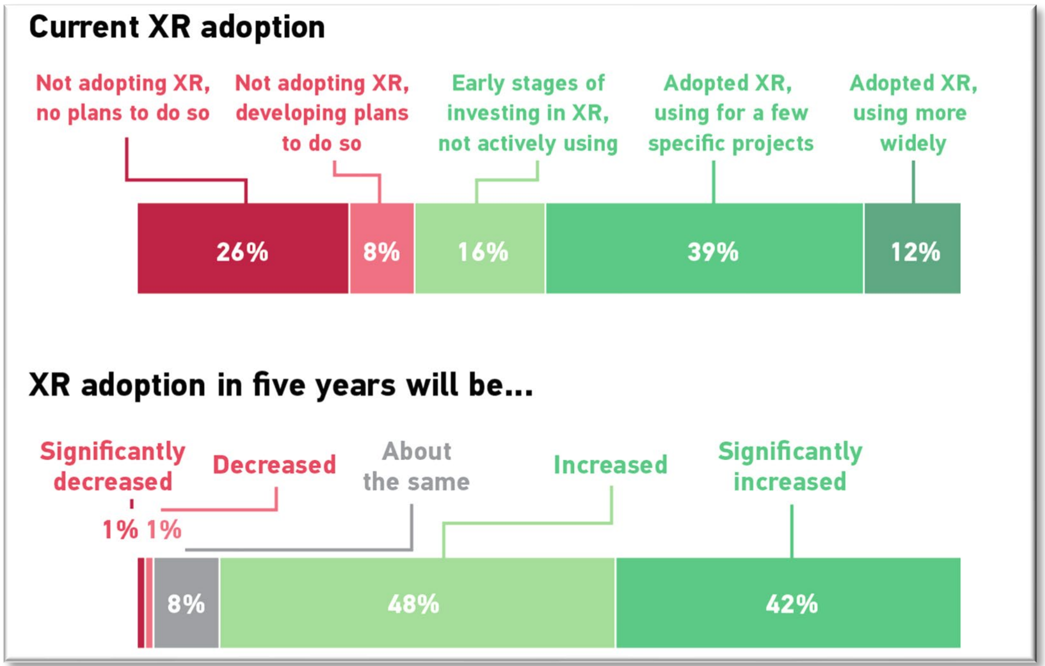
In addition, Oculus added a safety feature called the “Guardian System” (Oculus, 2020b). Allowing users to define a safe zone around the device before starting use. This zone does not limit or tie the device to any specific space or equipment allowing it to be safe and portable. Both systems have been so popular with consumers after a year both the Oculus Go and Oculus Quest are no longer sold having been superseded by a new model, the Oculus Quest 2 $299 (Oculus, 2020c). In this price range the headset is very competitive with other equipment that school districts and parents purchase like tablets, chemistry sets and basketball hoops.

XR Education Literature Review

As the hardware industry continues to climb Milgram’s class ranking of devices offering more function inside cheaper devices interest at an academic and research level continues to rise.

Figure 12

XR Adoption Rates



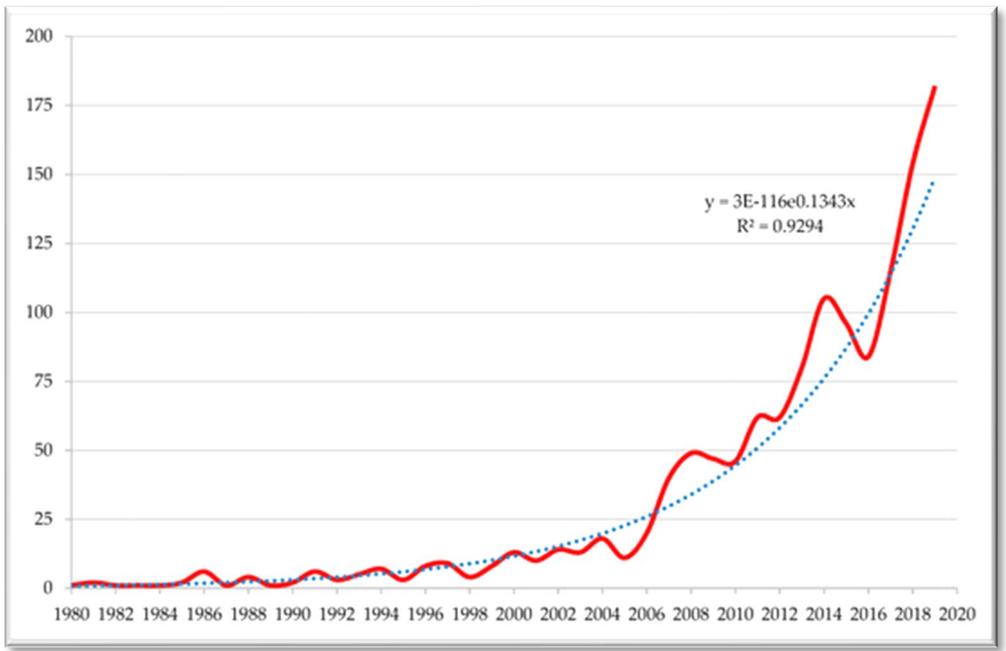
Note. Figure 12 shows 2021 and future XR adoption rates. Adapted from *Educause Quickpoll Results: XR Technology*, para. 6, by Mark McCormack, 2021, (https://er.educause.edu/articles/2021/12/educause-quickpoll-results-xr-technology). Copyright 2021 by Mark McCormack.

A recent EDUCAUSE survey from December 2021 indicates that current XR adoption at academic institutions is reported at 51%. It is estimated that in five years more than 90% of institutions will be involved in XR in categories such as, learning simulations, curricular on-campus activities, online learning, and research, shown in Figure 12. Short term expectations for XR technology implementations are reported to be student distance and on-campus learning oriented (McCormack, 2021).

XR research in education dedicated to different implications of Hiems qualities is plentiful and has increased dramatically especially in the past four years.

Figure 13

Evolution of Scientific Production (1980–2019)



Note. Figure 13 shows the evolution of scientific production from 1980 until 2020. Adapted from "Implications of Virtual Reality in Arts Education: Research Analysis in the Context of Higher Education," by Mariana-Daniela González-Zamar and Emilio Abad-Segura, 2020, *Education Sciences, Vol(10), Issue 9*, p. 225 (https://doi.org/10.3390/educsci10090225). Copyright 2020 by González-Zamar and Abad-Segura.

González-Zamar et al. (2020, p. 7) provided Figure 13 displaying 40 years of VR related published research. Revealing a significant upward trend in VR related published research. The red trend line denotes the number of articles written about VR in an education context, the blue line shows its goodness of fit. (González-Zamar & Abad-

Segura, 2020). Not only has the amount of research increased González-Zamar also discusses the breadth of XR research has been done investigating the effects of XR on the educational process across a wide spectrum of disciplines.

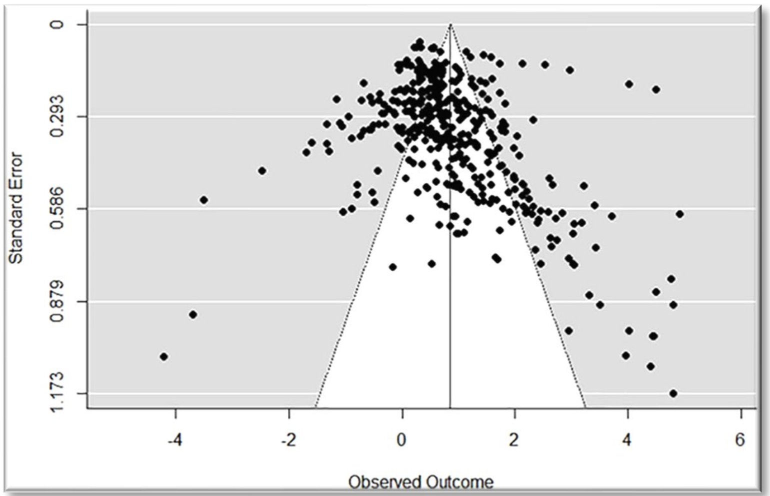
Complex or Abstract Topical Education

The stimulation of multiple sensory dimensions during the learning process of abstract or complex subject matter makes the learning more effective. The act of listening, seeing, and touching creates complex mental scaffolding structures providing for deeper learning. To do this the learner's intellect needs to interact with that reality at multiple experiential levels. (Raja et al., 2004). Several pieces of research discussed the difficulties and issues surrounding the teaching abstract concepts (Avilés-Cruz & Villegas-Cortez, 2019; Herman & Handzik, 2010) citing issues such as student motivation and engagement.

The use of XR in education has proven to be particularly successful at the transfer of knowledge of complex or abstract topics. The application of XR learning to primarily abstract concepts has shown significant results in knowledge transfer as shown in Figure 14 (Chernikova et al., 2020, p. 518). Mathematics and other STEM (science, technology, engineering, and mathematics) fields have shown significant improvements over traditional methods of instruction in these topics (Avilés-Cruz & Villegas-Cortez, 2019; Freeman et al., 2014; Jiménez-Hernández et al., 2020; Simonetti et al., 2020).

Figure 14

Funnel Plot of the Overall Effect of Simulations on the Acquisition of Complex Skills



Note. Figure 14 displays a scatter plot of the effects of simulations upon the acquisition of complex skills. Adapted from "Simulation-based learning in higher education: A meta-analysis," by O. Chernikova, N. Heitzmann, D. Holzberger, T. Seidel and F. Fischer, 2020, *Review of Educational Research Vol(90), Issue 4*, p. 518 (https://doi.org/10.3102/0034654320933544). Copyright 2023 by American Educational Research Association.

Applying critical thinking skills and problem solving to work a problem are core requirements for students in IP Networking. Researchers at Cisco Systems have put together an iVR (immersive virtual reality) system that promotes problem solving in IP Network design. This includes abstract concepts (labeled "magical" by the authors) like routing and subnetting. Combined with typical real-world concepts such as the mounting and cabling of physical equipment (aka "plug and chug" or "rack and stack"). Frezzo et al. states that, "situating and embodying problem solving both physically and conceptually, immersive VR can positively impact the teaching of problem solving in networking" (Frezzo & Waterman, 2020, p. 970).

3D Virtual Learning Environments

A 3D Virtual Learning Environment (VLE) is a technology enriched learning environment used to oversee and facilitate active learning exercises, through the delivery of pertinent content and instructional resources. Dillenbourg (2002) proposed the following list of features of a VLE:

- Feature 1: The VLE is created for specific instructional purposes. The use of a content management system allows for that information to be organized and retrieved. Moodle, BlackBoard and Canvas (Blackboard, n.d.; Canvas, n.d.; Moodle, n.d.) are examples of non-immersive virtual learning environments.
- Feature 2: A VLE provides an opportunity for collaboration and social interaction. In VLE students may gather for group collaboration in groupware like Teams, Zoom or Facetime (Apple, n.d.; Microsoft Teams, n.d.; Zoom, n.d.).
- Feature 3: The VLE is specifically expressed. The material presented can vary from web pages, video files to 3D immersive worlds.
- Feature 4: Students are not only consuming information and content they create, and share based on their own understanding to co-construct the virtual space.
- Feature 5: VLEs are not just for distance education learners. Traditional classroom activities and learners benefit from VLEs.

- Feature 6: VLEs combine multiple technologies and various learning methods. For example, integrating Blackboard content and access with GNS3 access creates a unique VLE for student learning (Blackboard, n.d.; GNS3, n.d.).
- Feature 7: Often VLEs imbricate with physical learning environments. For example, multiple students at the library using a large screen Teams device to have a group meeting with the remainder of their student group (Microsoft Teams, n.d.).

Response to the COVID-19 pandemic has been a virtual stampede to online instruction. A reported worldwide 1.2 billion K-12 students are out of the classroom (Unesco, n.d.) providing a large push to online instruction. This provides a serious impetus for funding and research in this area. While a large body of work supports VLEs as a learning medium that provides significant benefit to learning achievement (M. Chen et al., 2013; Lele, 2013; Moglia et al., 2016). Not all research confirms it, in a meta-review of VLEs research, completed as recently as 2020 (during the COVID-19 pandemic), indicates that VLEs are not a full replacement for in person instruction (Scavarelli et al., 2020). Leading to what some experts at the Pew Research Center are calling a “homework gap” (Schaeffer, 2021, para. 1) in student learning.

Adult Learning Motivation and Virtual Learning Experiences

As the workplace continues to evolve as a more complex landscape of technological and strategic issues arise it becomes necessary for all learners to become lifelong learners. This mindset prepares the learner not only for their current job but also future roles and professions, from fathers to truck drivers. Harvard Business Review states lifelong learners rather than begin motivated by fear of losing their jobs are, "employees who learned and grew in this way tended to exhibit what we have called the *passion of the explorer*." (Hagel III, 2021, para. 5).

However, Hagle III (2021) indicated when management was surveyed about why employees should have interest in lifelong learning, they admitted that employees were often motivated out of fear of losing their employment (Hagel III, 2021).

Issues surrounding adult learner motivation often have diverse issues such as learners with tighter time schedules and additional home responsibilities than traditional school aged students (Terebessy, 2018). These issues could encourage the adoption of VLEs as more adult-learners join the ranks of students. Several studies have shown positive changes in motivation and self-efficacy when learning in a VLE (Christopoulos et al., 2018; Makransky & Petersen, 2019).

Not all learners are inspired by the passion of the explorer, learner motivation is a troubling factor in the educational process. Appropriate VLEs and instructional material may be readily available, but we must wait until the learner is prepared to accept it. Learning motivation as a concept is problematic to measure due to the difficulty in operationally describing it. Though it cannot be directly observed, and thereby measured, it can be inferred from overt behavior of the learner (Touré-Tillery & Fishbach, 2014).

In the future employers expect traditional students and adult learners to obtain skills and competencies that go beyond a K-12 education. The National Association of Colleges and Employers research indicates that top skills employers are seeking include: Problem-solving skills, Ability to work in a team, Communication skills (written) and

Leadership (National Association of Colleges and Employers, 2017). Students may also need to continue past secondary education in order to obtain domain-specific knowledge and skills to make strategic professional decisions (Battelle for Kids, 2019).

VLEs are in use in a variety of disciplines both academic and professional, including network and system engineering (Barjis et al., 2012; Frezzo & Waterman, 2020), military (Lele, 2013), the medical field (Lopreiato & Sawyer, 2015; Moglia et al., 2016) and geography (M. Chen et al., 2013) overall results indicate a positive improvement in learners' accomplishments.

An example of VLEs, a recent article in the Cincinnati Enquirer (2021) highlighted domain-specific virtual learning. Dr. Rayn Moore, a pediatric cardiologist, led a team of 3D Virtual Reality designers at Cincinnati Children's Hospital. They created a 3D virtual model of the damaged heart of a 12-year-old patient. Dr. Ryan stated that every heart is different and typically testing out procedures would require 3D printing of a model organ. Each test procedure destroys the copied heart and requires the expensive fabrication of another model organ. The VLE allowed doctors to test and retest different methods of repairing the organ without additional expense. Using the VLE doctors were able to plan and test a procedure that, "otherwise taken several surgeries" (Cincinnati Enquirer, 2021, para. 10).

Theoretical Frameworks

Plato and Aristotle, two and half millennia ago, began an explanation of human perception and understanding that continues to this day. Though Aristotle is primarily attributed as an empiricist, truth discovered via the human senses, and Plato as a rationalist, truth through reason, they were a few of the first to begin the systematic process of defining cognition or how to make sense of the world around them (Stevenson et al., 2018).

As a mere user of learning theories and theory frameworks my effort here is to list and *briefly* detail the theories that I leveraged during my research. This review of supporting material draws from the vast pool of significant research that has been done surrounding learning theories, the progenitors of those theories and the application into my perspective and research. As humans shape technology so it shapes our understanding.

For my research, I implemented an in-person blended learning curriculum to convey primary principles of IP networking. Designed and developed VR software, as an instructional tool to deepen that learning. The software, called Virtual Reality IP Subnetting (VRIPS), implemented on the Oculus Quest platform was used to engage students in active learning using more sensory modality than previous learning methods. The software development is based on constructivist tenants, Mayer's Theory of Multimedia Learning and Keller's ARCS Motivational principles. Post intervention application of the NASA-TLX subjective workload measurement tool was utilized to assess subjective cognitive load during the VRIPS learning intervention.

To better understand the basis that virtual reality (VR) learning stands upon, a deeper context of constructivism and constructivist learning is reviewed. This foundational knowledge provides a frame of reference for later topical pedagogical discussion.

Constructivism

Constructivism in education posits that learners build or construct new knowledge and understanding through linking new information with what is previously known (Cobb, 1994; Nola & Irzık, 2005). Learning occurs through and during physical interaction with the environment and physical and social interaction with other learners.

Founders of Constructivism

There is an ongoing debate among researchers about the inclusion of John Dewey as a founder of constructivism. Antagonists view Dewey as only a pragmatist and reject the concepts of knowledge building and metacognition (Kivinen & Ristela, 2003). While others embrace a less strict understanding of Dewey's theories and embrace them as the beginnings of constructivist learning theories (Hickman et al., 2009). After reading about John Dewey and reading portions of his manuscripts and theories I believe the latter. That the genesis of constructivism comes from John Dewey's when he states that people learn based on constructing meaning from experiences followed by reflection to assimilate that meaning into their own perspective (Splitter, 2009). John Dewey's theories and writings are a significant contribution to the foundation of constructivism, for this reason I have included him in this document.

Other early pioneers in the field of Constructivism were Jean Piaget and Lev Vygotsky. Together their primary learning theories are attributed with the creation of modern constructivism. Each has unique perspectives on learning and the construction of knowledge. Piaget's contribution of schemas for the construction of knowledge combined with Vygotsky's Zone of Proximal Development (ZPD) and More Knowledgeable Other

(MKO) assistance create a learning method that is both durable and powerful for instruction and educational research. Bruner's contribution of scaffolding theory sharpens the application of the previous theories and provides a context for instrument and instructional content creation.

John Dewey. John Dewey (1859-1952) was an American psychologist and educational reformer, who held strong beliefs about politics, communication, and education. His primary focus was upon society and education, both of which he felt needed reform based on a theory of learning through doing (Festenstein, 2005). Dewey articulated the connection between society and education while advocating for reforms with statements in *My Pedagogic Creed* (1926), "education is the fundamental method of social progress and reform." (Dewey, 1926, p. 16).

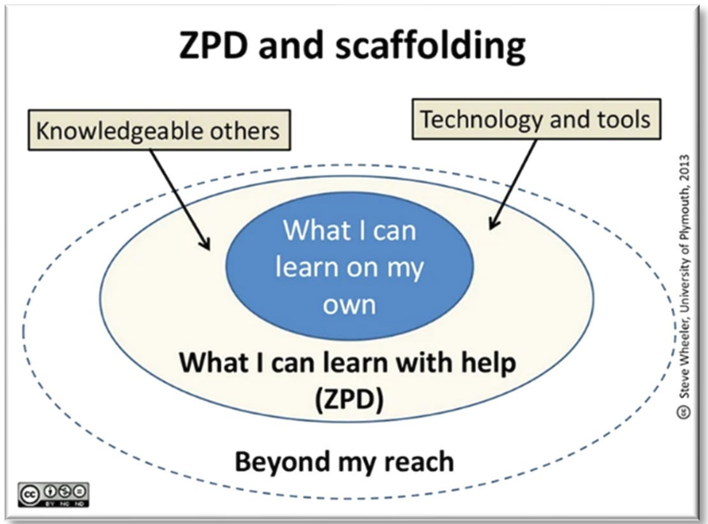
Dewey held that, "the educational process has two sides" (1926, p. 4) both a psychological and sociological. The educational process must use both sides to achieve learning or "evil results following" (Dewey, 1926, p. 4). Meaning that using the learners' own interests and curiosity to start and sustain the process of education or the process will fail. The social aspects of education allow the learner to connect what is learned within the context of the larger society.

Dewey's *The School and Society* (1899), now over one hundred years ago, insisted that students sitting in rows, rote memorization and recitation was old. Students should be actively engaged in learning and in the process of learning. Dewey was an ardent follower of democracy and believed deeply that a cooperative learning environment developed a thriving cooperative democratic society. He proposed using small groups of students with similar interests to engage in relevant learning activities guided by both more experienced learners and instructors.

Lev Vygotsky. Lev Vygotsky (1896-1934), a Russian self-taught child psychologist, proposed that knowledge acquisition is a social interactive experience. Each of these actions is part of social interaction and exploration that allows the learner to put the new knowledge into context. Vygotsky's primary contribution to Constructivism is the Zone of Proximal Development (ZPD). The ZPD, shown in Figure 15 (McLeod, 2008), was defined by Vygotsky as, "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86).

Figure 15

Zone of Proximal Development



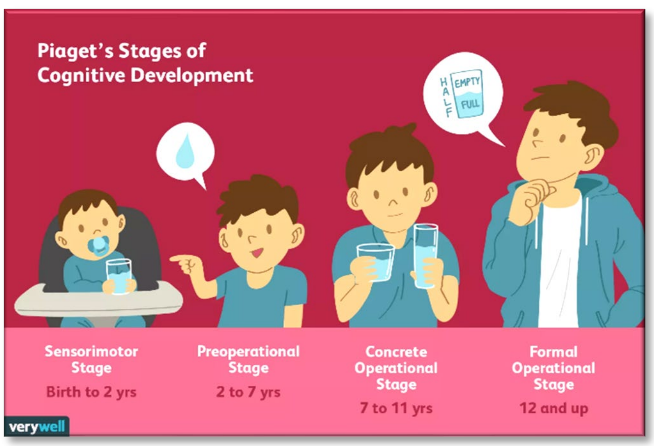
Note. Figure 15 displays Lev Vygotsky's Zone of Proximal Development. Adapted from *Lev Vygotsky's Sociocultural Theory* by S. Wheeler, 2015, (https://www.simplypsychology.org/vygotsky.html). CC BY-NC.

This distance between what is known and unknown could be navigated by the learner through interaction with peers, other higher and lower knowledge learners, the environment, and other outside resources as shown in Figure 1. To support the ZPD often a More Knowledgeable Other (MKO: teacher or peer) could assist the learner in a supported environment before using the skill independently (McLeod, 2008). This situation created a dynamic social and educational or sociocultural context for knowledge creation and processing (Kurt, 2020; Seng, 1997).

Jean Piaget. Jean Piaget (1896-1980) a Swiss psychologist, proposed that learning is both an intrinsic (coming from within) activity and an extrinsic (teacher or environmentally taught) activity and that both are needed for optimal learning (Mooney, 2013). Piaget claimed that learners construct their knowledge by giving meaning to the experiences (people, place, things) of their world. He believed that learners learn best when they are actively involved in the action rather than passively receiving explanations from an instructor (National Research Council, 2000) in this way very similar to John Dewey's statements. He was a student of Marian Montessori and followed her work believing that learners need meaningful work and must also do the work for themselves (Mooney, 2013).

Figure 16

Piaget's Stages of Cognitive Development



Note. Figure 16 displays Piaget's four stages of cognitive development. Adapted from *Piaget's 4 Stages of Cognitive Development Explained*, by Kendra Cherry and Joshua Seong, 2023, para. 3 (https://www.verywellmind.com/piagets-stages-of-cognitive-development-2795457). Copyright 2023 by Dotdash Media, Inc.

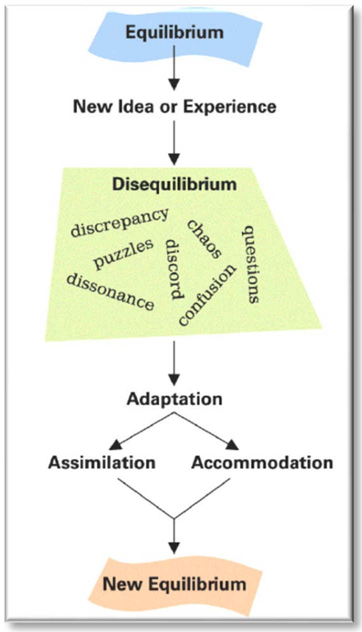
Piaget is best known for his Theory of Cognitive Development; this theory details the four stages of cognitive development (Sensorimotor stage: birth to 2 years, Preoperational stage: ages 2 to 7, Concrete operational stage: ages 7 to 11, Formal operational stage: ages 12 and up) as illustrated in Figure 16 (Cherry & Seong, 2023, para. 3).

During all four stages the learner utilizes and creates mental models, Piaget called schemas, to understand and categorize new ideas and place them in context with existing information (Mooney, 2013). Scott and Cogburn (2021) refined the definition of schemas asserting that schemas include both a category of knowledge and the process of obtaining that knowledge.

Piaget believed that cognitive development required four parts: biological maturation, physical environment experience, social environment experience, and equilibration. While the first three are reasonably self-explanatory, the fourth, equilibration, is the central factor and driving force in cognitive development. Equilibration is the need to create an optimal state of adaptation between cognitive structures and the environment. Cognitive development takes place only when disequilibrium or cognitive conflict occurs (Duncan, 1995).

Figure 17

Cognitive Disequilibrium



Note. Figure 17 shows the stages of cognitive disequilibrium. Adapted from *The Developing Person Through the Life Span* (p. 214) by Kathleen Stassen Berger, 2019, Worth Publishers. Copyright 2020 by Worth Publishers.

To accomplish the task of cognitive equilibration two sub-components are used: assimilation and accommodation as shown in Figure 17 (Berger, 2019, p. 214). Assimilation occurs when the learners must fit something new into the existing cognitive structure. This may come in the form of changing reality to process fit it into current schemas. Thereby making it fit within the current cognitive schemas. Accommodation is the process of changing cognitive structures to understand the information processed. In this situation the learner will update cognitive schemas with new information learned (Schunk, 2014; Woolfolk, 2021).

Figure 18

Piaget's Four Stages

STAGE	APPROXIMATE AGE	CHARACTERISTICS
Sensorimotor	0–2 years	Learns through reflexes, senses, and movement—actions on the environment. Begins to imitate others and remember events; shifts to symbolic thinking. Comes to understand that objects do not cease to exist when they are out of sight—object permanence. Moves from reflexive actions to intentional activity.
Preoperational	Begins about the time the child starts talking, to about 7 years old	Develops language and begins to use symbols to represent objects. Has difficulty with past and future—thinks in the present. Can think through operations logically in one direction. Has difficulties understanding the point of view of another person.
Concrete Operational	Begins about first grade, to early adolescence, around 11 years old	Can think logically about concrete (hands-on) problems. Understands conservation and organizes things into categories and in series. Can reverse thinking to mentally "undo" actions. Understands past, present, and future.
Formal Operational	Adolescence to adulthood	Can think hypothetically and deductively. Thinking becomes more scientific. Solves abstract problems in logical fashion. Can consider multiple perspectives and develops concerns about social issues, personal identity, and justice.

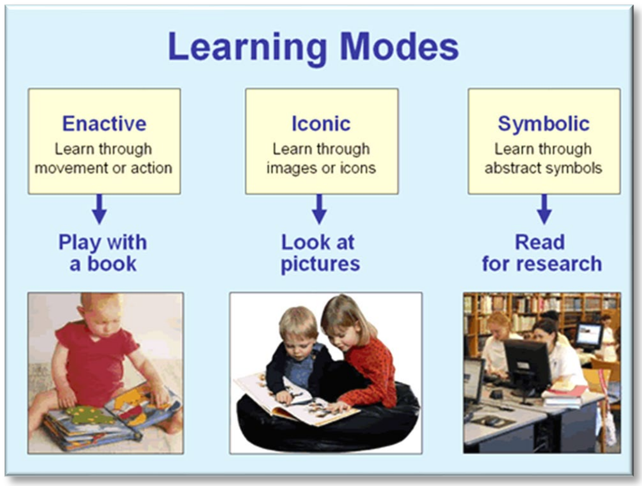
Note. Figure 18 shows a table detailing Piaget's developmental stages. Adapted from *Educational Psychology* (p. 76), by Anita Woolfolk, 2021, Pearson. Copyright 2021 by Pearson Education Limited.

Woolfolk's (2021) diagram provides more detail for each of Piaget's four stages of cognitive development as shown in Figure 18. The earliest of the category is the Sensorimotor stage, ages 0-2 years of age, is primarily driven by five sensory inputs (seeing, hearing, moving, touching, tasting). During this stage basic concepts like object permanence and goal-directed actions are discovered (Berger, 2019). The Preoperational stage, 2-7 years of age, semiotic functions are developed. Semiotic functions are the symbolic representation of concepts needed to communicate with others. Often at this stage learners have difficulty decentering their schemas from their own immediate perspective of how the environment appears from their current perspective (Woolfolk, 2021). The third stage called, Concrete Operational, for learners 7-11 years of age, Piaget encouraged independent hands-on learning (Blake & Pope, 2008) during this stage of learning. Learners can express their understanding and recognition of the stability of the physical world, realization that parts of that world can be changed and still retain much of their original characteristics, and that those changes can be reversed if needed (Woolfolk, 2021). The ability to focus and discern specific qualities or alignment of order of a group of objects, classification, and seriation, are mastered at this stage as well. Piaget's fourth and final stage is called the Formal Operations stage and starts at 11 and continues throughout adulthood. At this point the learner can imagine a situation that could be rather than being limited only to what is in front of them physically. A learner utilizing formal-operational thinking can consider a hypothetical situation and reason both deductively and inductively. Abstract formal-operational thinking is required for much of the higher level mathematics (Woolfolk, 2021).

Jerome Bruner. More recent researchers have helped to refine these Constructivist learning theories and concepts. Jerome Bruner, an American psychologist, had a long and impactful career in educational and cognitive psychology. Bruner's primary contributions were in knowledge representation and Scaffolding Theory. Burner proposed three modes of knowledge representation, illustrated in Figure 19.

Figure 19

Learning Modes



Note. Figure 19 shows learning modes. Adapted from *fassiya*, 2013 by Aishath Abdhulqadir, (https://fassiya.wordpress.com/2013/11/10/1-by-providing-examples-discuss-how-a-teacher-can-help-become-lifelong-learners). Copyright 2013 by Aishath Abdhulqadir.

Enactive representation (action-based), Iconic representation (image-based) and Symbolic representation (language-based). He suggests that when a learner encounters new material the learner progresses through the three stages; even adult learners use this process to a greater or lesser degree (Abdhulqadir, 2013; Bruner, 1966).

One of Bruner's contributions to constructivism was Scaffolding Theory (Wood et al., 1976) as stated by Bruner is a,

> process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts. This scaffolding consists essentially of the adult 'controlling' those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence. (Wood et al., 1976, p. 90).

Opposing Constructivism

One of the largest criticisms of constructivism and constructivist curriculum design and learning methods is the difficulty in providing proper scaffolding and structure at correct times for the learner. Critics point to Discovery Learning as an inefficient process of student learning (Osborne, 2021). They also point to radical constructivism that utilizes learning methods that are more structurally relaxed, allowing the learner to have more agency in the direction of learning at the cost of topical depth resulting in poor student learning (Matthews, 2012). While this can appear to be a conflict, in most cases, it is a failure to accurately describe the learning process to the student.

Supporting Constructivism

Constructivist learning environments often are tailored by the faculty to help each student build their plateau of understanding by leveraging the student's innate curiosity in the universe to drive the learning process (McLeod, 2019b). Faculty and students engage in a two-way dialog that provides interactive learning. This interaction often encourages students to direct their own learning to new areas or new topics that are built from what the student already understands. The faculty guides and fills in knowledge gaps while searching for information (Lombardi & Shipley, 2021). At the same time the faculty is keeping track of the overall learning direction.

According to Olusegun (2015) a constructivist learning environment provides deeper learning because the learner is actively involved in the learning process rather than passive listeners. Rather than focusing on the memorization of facts, a constructivist environment concentrates on thinking and understanding. The organizational process of understanding, learning to learn, makes the process of learning transferable to new topics and in new environments and contexts. Peer grouping of learning activates social communication skills in addition to providing a larger group of collaborative task partners.

Constructivism's Impact Upon My Research

While Vygotsky's social-constructivist theories influence the blended learning portion of my research process where other learners and an MKO is indirectly or directly impacting the learning process during the formative concept scaffolding construction period. The quasi-experimental portion of the treatment occurred in virtual reality where each participant functioned in a solo learner space. For this reason, Piaget's learning theories are more applicable as they have less focus on the social aspects of the learner's environment and are therefore more applicable in an individual learning mode. Bruner's scaffolding theory dovetails quite well with Vygotsky's ZPD and MKO theories to create a more structured learning environment that can be accurately reflected in instructional materials and in the creation of instrumentation for research. For me, this means viewing those theories through a more Piaget-style solo lens while implementing them in VR.

Cognitive Theory of Multimedia Learning

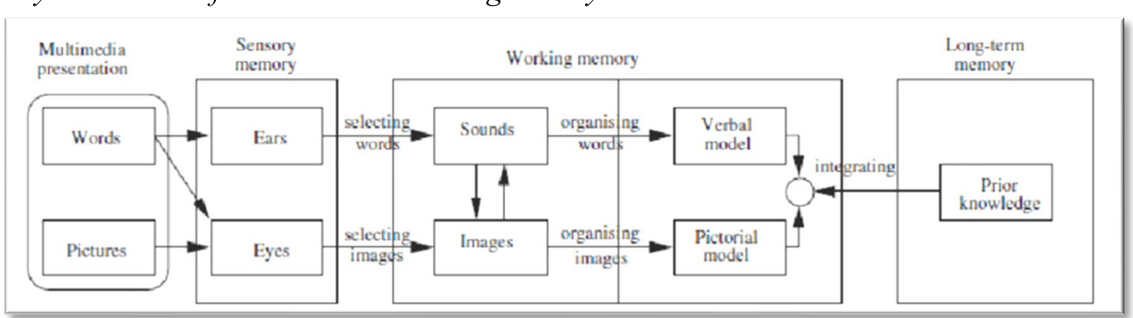
Mayer's Cognitive Theory of Multimedia Learning (2014), provides additional instructional methods and techniques for researchers and instructional designers alike.

Mayer posits, "People learn more deeply from words and pictures than from words alone. This assertion – which can be called the *multimedia principle* – underlies much of the interest in multimedia learning" (Mayer, 2014, p. 83).

There are three primary assumptions in Mayer's theory. First, is the dual-channel assumption or the idea that the human brain uses distinct and separate sensory processing channels for visual sensory information and a different channel for auditory sensory information. Second, the Limited-Capacity Assumption states that each sensory input channel has a limited capacity to process input during the creation of new intrinsic mental models. Third is the Active Processing Assumption that learning is an active process of finding relevant incoming information, organizing that information into a cognitive structure, and integrating information with existing knowledge (Mayer, 2014). Figure 20 shows Mayer's process of multimedia learning (Mayer, 2014, p. 83).

Figure 20

Mayer's Model of Multimedia Learning Theory



Note. Figure 20 displays Mayer's Model of Multimedia Learning Theory. Adapted from *The Cambridge Handbook of Multimedia Learning* (p. 83), by Richard Mayer, 2014, Cambridge University Press (https://doi.org/10.1017/CBO9781139547369). Copyright 2014 by Cambridge University Press.

Three memory stores are indicated by the theory: sensory memory, working memory and long-term memory. Learning involves all three in concert. However, Mayer indicates there are limitations on each type of memory. Sensory memory is short-lived and contains only unprocessed images and words. Working memory has a slightly longer duration and is used for organization and concatenate multiple inputs and from the sensory memory for new material and long term for contextual concepts. While long term memory is the storage of the learner's accumulated knowledge. This memory has a nearly limitless duration, however parts of the information must be shifted into the working memory to actively process it (Mayer, 2014).

Multimedia instruction attempts to expand the capacity of working memory through multiple sensory channels, each with its own short time frame, into working memory for processing. Five cognitive processes are used in working memory: selecting words, selecting images, organizing words, organizing images, and integration. The completed mental structure can be integrated with prior knowledge in long term memory (Mayer, 2014).

Mayer's theory is relevant to my research not only because VR could provide additional sensory modalities to provide deeper learning. The theory also includes a discussion of the three types of demand upon cognitive capacity, shown in Figure 21 (Mayer, 2014, pp. 92–93), that could affect deeper learning.

Figure 21

Cognitive Demands

Name	Description	Caused by	Learning processes	Example
Extraneous processing	Cognitive processing that is not related to the instructional goal	Poor instructional design	None	Focusing on irrelevant pictures
Essential processing	Cognitive processing to represent the essential presented material in working memory	Complexity of the material	Selecting	Memorizing the description of essential processing
Generative processing	Cognitive processing aimed at making sense of the material	Motivation to learn	Organizing and integrating	Explaining generative processing in one's own words

Note. Figure 21 displays types of cognitive demand upon a learner. Adapted from *The Cambridge Handbook of Multimedia Learning* (p. 92-93), by Richard Mayer, 2014, Cambridge University Press (https://doi.org/10.1017/CBO9781139547369). Copyright 2014 by Cambridge University Press.

Extraneous processing refers to any cognitive function that does not directly apply to the learning objectives. Poor quality instructional material can require the student to provide additional cognitive function to filter out unnecessary or irrelevant material before transferring the remaining material to working memory. Essential processing provides the cognitive function to take sensory input and build the coherent mental model in working memory. The complexity level of concepts requires additional processing in working memory. Generative processing references the cognitive processing to make sense of material in working memory before transfer to long term memory. It is well known that each learner has different background, skills and cognitive capabilities because of these differences a multimedia instruction might overload one learner and not another (Mayer, 2014). Instructional designers struggle with the creation of material that is appropriate to the learner's cognitive level without overloading their working memory capacity.

Bodily-Kinesthetic Intelligence

Mayer's theory posits a visual and audio channel, I assert adding a third modality to Mayer's multi-modal approach of visual and auditory, a kinesthetic modality. Howard Gardner proposes the concept of Bodily-Kinesthetic intelligence stating, "Characteristic of such an intelligence is the ability to use one's body in highly differentiated and skilled ways, for expressive as well as goal-directed purposes" (Gardner, 2011, p. 218) followed by, "the capacity to work skillfully with objects, both those that involve the fine motor movements of one's fingers and hands and those that exploit gross motor movements of the body" (Gardner, 2011, p. 218).

Gardner goes on in his manuscript to detail and define the roles that require the mastery of the body and motion such as: dancers, musicians, construction workers, and athletes among many other functions. Following this with a discussion about how those skills are obtained specifically during the initial use of a new object or tool. A learner needs to carefully join information assimilated through both sight, body perception and bodily motion to more deeply learn the concept being presented (Gardner, 2011).

I propose that a VR enriched curriculum can encompass Mayer's structure of Multimedia Learning Theory and extend it through the application of additional modal dimensions of learning.

Multimedia Learning and Kinesthetic Intelligence's Impact Upon My Research

The application of Mayer's and Gardner's theories leverages the dual-channel assumption, limited capacity, and active processing during the blended-learning sessions and VR instructional instrument. Through varying the modality of information, visual, auditory, *and* kinesthetic I believe leads to deeper learning of IP networking.

A second application of Mayer's theory, especially demands on cognitive load, is during the post-treatment cognitive load assessment. Often in a computer-based learning environment the learner is required to simultaneously carry out several meta-cognitive strategies to process situations and balance strategies to incorporate new information. The addition of too much multimedia stimuli could limit learning opportunities due to extraneous processing leading to overloaded cognitive capacity (Ang et al., 2007).

Blended Learning Environments

Blended learning environment as a term and concept has evolved over time and throughout the literature. Earliest definitions referred to blended learning through the use of multi-modal avenues to present learning materials (Garrison & Vaughan, 2008; Hall, 2003; Muianga, 2005; Singh, 2003). The current definition typically used is a combination of traditional learning in-person learning environment combined with supplemental learning technology (Powell et al., 2015). Christensen et al. (2013) defines a blended learning program as,

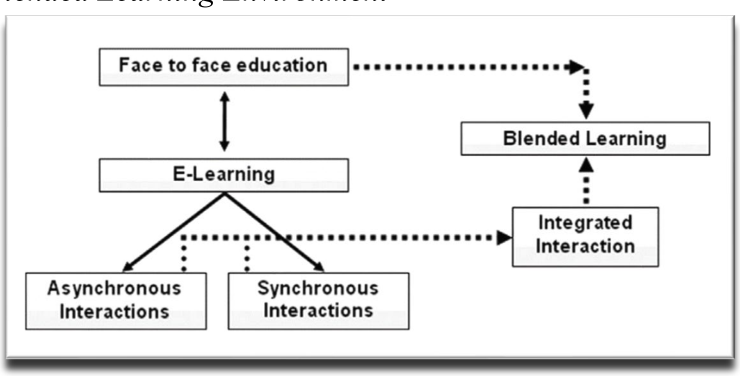
> a formal education program in which a student learns at least in part through online learning with some element of student control over time, place, path, and/or pace and at least in part at a supervised brick-and-mortar location away from home. The

> modalities along each student's learning path within a course or subject are connected to provide an integrated learning experience. (Christensen et al., 2013, p. 7)

This definition can be contrasted with a learning environment that is entirely online (e-learning) or completely conducted face-to-face (traditional learning style) (Yagci, 2016). Blended learning environments as depicted in Figure 22 by Deperlioglu and Kose (2013, p. 330) include face-to-face instructional delivery combined with technology e-learning for content delivery. The result is an attempt to provide deeper learning and engagement for learning for the learner by providing a more meaningful learning experience and improved educational process (Thorne, 2003).

Figure 22

Blended Learning Environment



Note. Figure 22 shows the blended learning environment process. Adapted from "The effectiveness and experiences of blended learning approaches to computer programming education," by Omer Deperlioglu and Utku Kose, 2013, Computer Applications in Engineering Education, Vol(21), Issue 2, p. 330 (https://doi.org/10.1002/cae.20476). Copyright 2023 by John Wiley & Sons, Inc.

Keller's ARCS

Student motivation and engagement is a composite mosaic of interacting forces both internal and external to the learner. Creation of effective instructional interventions and instruments that engages and motivates learners and ensures the continuity of both throughout the process requires the collection and analysis of empirical data with an eye towards understanding the underlying inclinations of the learner (W. Huang et al., 2006; Keller, 2010; Pappas, 2015). Several studies have shown that motivational issues provide sway over learner instructional outcomes because they are fundamental issues that push learner performance (Ames, 1992; Anderman & Maehr, 1994). Keller's theory of Motivation, Volition, and Performance (Keller, 2008) details a fluid and interactive relationship between motivational components which has an impact on the effort of learning.

Instructional design must include thoughtful examination of the student motivational aspects that inaugurate and continuously facilitate deep learning affecting student outcomes (Ames, 1992; Anderman & Maehr, 1994). A thoughtful balance of intrinsic and extrinsic motivation and motivational theory must be considered when creating effective instructional material.

Intrinsic motivation has been defined as conducting and activity for an innate internal reason rather than an being impelled to by an outside goal (Keller, 2008; Park, 2017; Ryan & Deci, 2000). An intrinsically motivated person engages in an activity for its own sake. For example, a mountain climber might enjoy the thrill of achievement or the satisfaction of completion at their latest mountain summit.

Conversely, extrinsic motivation has been defined as completing in order to achieve a goal in order to attain a reward or avoid punishment (Keller, 2008; Park, 2017). For example, an employee that is working because they fear management sanctions or punishment.

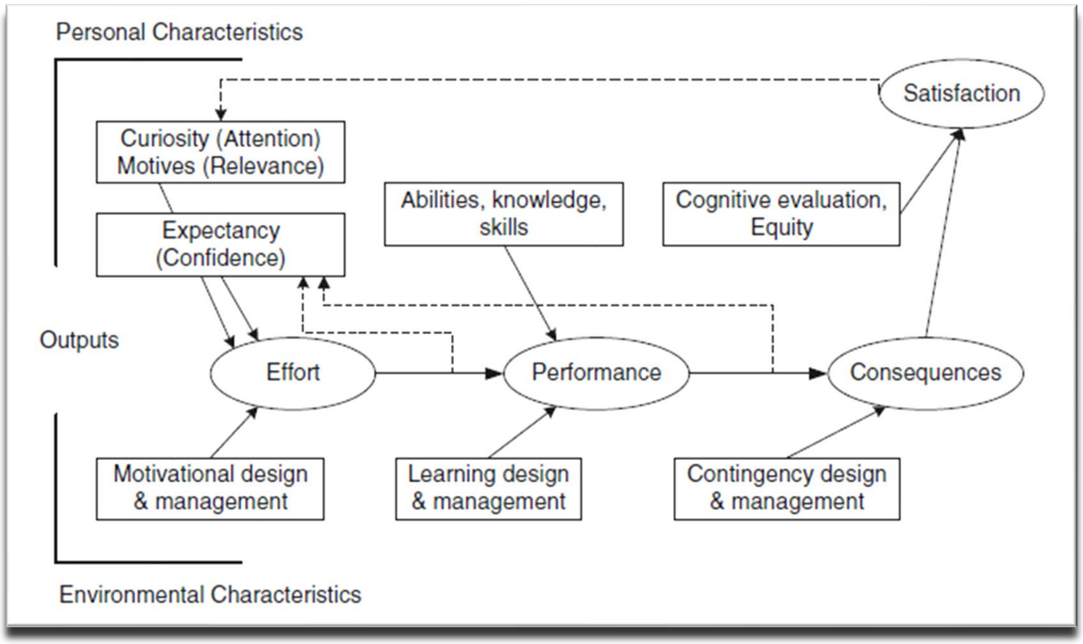
One of the most common dangers of extrinsic rewards is the overjustification effect. If a learner is intrinsically motivated to learn a subject and is also motivated by external rewards at the same time, there is the danger that the student loses their intrinsic motivation for this task (Deci, 1975; Ryan & Deci, 2000). Depending on the situation either type of motivation can be used when modifying behavior, intrinsic motivation is usually seen as ideal because of its sustainability and inherent reward structure.

Factors external to the learner can have complex interactions with student learning motivation. It becomes critical for faculty and instructional designers to identify sources of reduced motivation in any given learning context. John M. Keller's (2010) ARCS model is one of the most well-known motivational design models for the study of learner attitudes and engagement levels (Huang et al., 2006; McMahon, 2019; Pappas, 2015; Park, 2017). The use of which could provide researchers insight into understanding what would motivate learners to stay engaged thus providing deeper learning.

Keller ARCS model states that learner motivation is primarily affected in four functions: Attention, Relevance, Confidence, and Satisfaction (2010). Interactions between each of the four functions along with additional factors that influence the process of motivation are illustrated by Keller (2010, p. 6) in Figure 23.

Figure 23

Keller's Process of Motivation



Note. Figure 23 shows Keller's process of student motivation. Adapted from *Motivational Design for Learning and Performance* (p. 6), John M. Keller, 2010, Springer (https://doi.org/10.1007/978-1-4419-1250-3). Copyright 2010 by Springer Science+Business Media, LLC.

Small (1997) summarizes the ARCS model with the following:.

- **Attention:** strategies for arousing and sustaining curiosity and interest.
- **Relevance:** strategies that link to learners' needs, interests, and motives.
- **Confidence:** strategies that help students develop a positive expectation for successful achievement.
- **Satisfaction:** strategies that provide extrinsic and intrinsic reinforcement for effort.

Keller (2010) states that attention can be obtained in two ways. First, perceptual arousal gains the learners' attention through the arousal of senses and emotions. Second, utilizing inquiry arousal to simulate thinking may be created by delving into a situational problem that is only solved through knowledge seeking.

The second category is, relevance, or "why is this meaningful to me?". Instructional design should strive to relate to the learners' previous experience and needs. For learners to make sense of the material they need to see it first as an activity that helps them to what they perceive as success. Keller (2010) state there are six major strategies for relevance: Experience, communicating to the learner how learning the material uses their existing skills. Present Worth, how the material helps the learner in the short term. Future Usefulness or how the material helps the learner farther into the future. Need Matching, using the dynamics of achievement to motivate learning. Such as risk taking and group affiliation. Modeling of behavior, for example, having guest lectures or using videos of acclaimed and accomplished experts in the field. Finally, choice, allowing the student to have some control over the methods to knowledge pursuit (Small, 1997).

Keller's (2010) third primary category is confidence. Ryan and Deci (2000) state that believing oneself to be competent is a basic human need. It can be a difficult task to create instructional material that encourages a learner to stretch mind and skills without setting the learner up for failure. The three subcategories reported are: Success Opportunities, the creation of opportunities that allow learners of all abilities to succeed at challenge appropriate tasks (Keller, 2010; Pappas, 2015). Personal control is encouraged by helping the learner understand that the learners' own effort determines achievement and fostering a learning environment where that is possible.

Keller's (2010) final primary category is satisfaction. Learning must be rewarding to provide a sense of achievement, praise, or entertainment. The three subcategories for this are: Natural consequences or how to create a meaningful occasion for learners to effectively demonstrate their newly obtained knowledge. Positive consequences, the provision of reinforcement to the learner's successful use of knowledge. Equity, setting context for achievements that maintain consistent standards and consequences for success.

ARCS's Impact Upon My Research

While the direction of my research is not specifically directed towards student motivation and engagement, those issues arise in the creation of blended learning and VRIPS design and creation. It is my intent to leverage Keller's ARCS principles imbuing aspects into my blended-learning curriculum and during the design of the VR instructional instrument.

Subjective Cognitive Load Testing

Cognitive Load testing cannot be discussed appropriately in this context without first covering John Sweller's (1994) Cognitive Load Theory and Richard E. Mayer's Cognitive Theory of Multimedia Learning (2014). When used in conjunction they provide the framework needed to use the NASA-TLX Subjective Cognitive Load Test (Hart & Staveland, 1988) self-reported survey instrument in an appropriate manner.

Cognitive Load Theory

Sweller and Paas published work appears within Mayer's (2014) *The Cambridge Handbook of Multimedia Learning* providing an exploration of concepts in multimedia cognitive load theory. Sweller's (1994) Cognitive Load Theory attempts to discern the best conditions for learners to retain information they received. He expresses cognitive load as the number of memory schemas, or elements, able to be held in working memory at one time. Because working memory has a limited capacity, instructional design methods should not attempt to overload it with additional material that does not contribute to learning in a direct fashion. Mayer (2014) summarizes it thus, "the sum of extraneous processing plus essential processing plus generative processing cannot exceed the learner's cognitive capacity" (Mayer, 2014, p. 94).

Sweller (2010) provides three separate types of cognitive load that should be avoided by instructional designers so lower risks of overwhelming the learner. All three types of cognitive load deal with the accumulation, store, and implementation of secondary biological information. The three types Sweller defines are intrinsic, extrinsic, and germane cognitive load upon the learner.

Intrinsic cognitive load is the result of the learning process related to a specific topic. He posits that all learning has an inherent difficulty, the sum of which cannot be altered. However, the learning schema can be broken down into sub-schema for instructional purposes allowing the learning an opportunity to process each sub-schema in an attempt to avoid cognitive overload (Sweller, 2010). Additional effort on the part of the instructional designer must be taken breaking down the topic and time after all sub-schema have been processed to reassemble the sub-schema with the learner.

Extrinsic cognitive load relates to the cognitive load put upon the learner processing the learning material during the instructional process. This level of cognitive load is as a direct result of processing of instructional materials (Sweller, 1994). Sweller suggests that because the single cognitive resource is being utilized to process extraneous load there are less resources available to process intrinsic and germane load, needed for deep learning. Because of this relationship instructional designers should be aware in difficult learning situations to reduce as much extraneous load as possible (Ginns, 2006).

Germane load is the level of cognitive load required for the creation, organization and integration of schemas (Sweller et al., 1998). Mayer refers to this as "'effective' cognitive load" (Mayer, 2014, p. 62) as it refers to the necessary working memory needed to process intrinsic cognitive load. A colleague and co-author with Sweller, Fred Paas, conducted research in 2010 indicating given three types of instructional materials, worked examples, completed problems, and discovery practice) learners performed best in post instructional assessment having used worked examples (Paas et al., 2003).

NASA-TLX

In 1998 Sandra Hart and Lowell Staveland, while working for NASA, created a multi-item post intervention questionnaire called NASA-TLX (Hart & Staveland, 1988; So, 2020) that is used to measure the potential for cognitive capacity overload. A number of research pieces have been conducted to confirm its ability to deliver valid data results (Hart, 2006; Said et al., 2020).

The NASA Task Load Index (NASA-TLX) is a standardized self-assessment survey assessment tool for measuring a subjective mental workload. This allows the researcher to determine the mental workload of a participant during the performance of a task(s). The instrument ranks performance across six scales to determine the overall mental workload (MWL). It uses a weighted average of six workload six scales. They are reported by Stanton (2006) below:

1. **Mental demand:** how much thinking, deciding, or calculating was needed in the task?
2. **Physical demand:** amount and intensity of physical activity required to complete the task?
3. **Temporal demand:** the amount of time pressure involved in completing the task?
4. **Effort:** how hard does the participant have to work to maintain their level of performance?
5. **Performance:** perceived level of success in completing the task?
6. **Frustration level:** how insecure, discouraged, or secure or content did the participant feel during the task?

Participants are asked to rate their score on an interval scale from low (1) to high (20). Utilizing a paired comparison procedure that involves presenting fifteen pairwise combinations to the participants (Fig 22 and 23). Requiring they select the scale from each pair that had the most effect on workload during that task being studied. The pairwise combination accounts for two sources of inter-rater variability. First, the perceived differences in workload between raters. Second, the difference of workload source between the tasks (Hart & Staveland, 1988; Stanton et al., 2006). Examples of NASA-TLX rating scale and survey instrument are shown in Figure 24 and Figure 25 (Hart, 2006, p. 5).

Figure 24

NASA-TLX Rating Scale

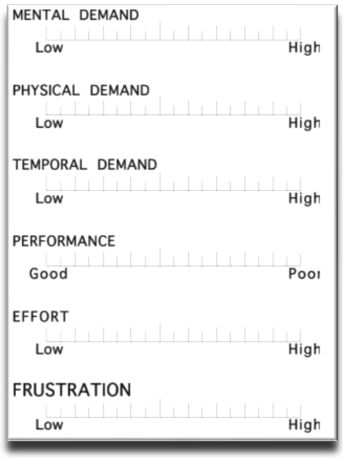
RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Note. Figure 24 shows NASA-TLX rating scale. Adapted from "Nasa-Task Load Index (NASA-TLX); 20 Years Later," by S. G. Hart, 2006, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting Vol(50), Issue 9*, p. 909 (https://doi.org/10.1177/154193120605000909). Copyright 2006 by Human Factors and Ergonomics Society.

Figure 25

NASA-TLX Survey Instrument



Note. Figure 25 shows NASA-TLX survey instrument. Adapted from "Nasa-Task Load Index (NASA-TLX); 20 Years Later," by S. G. Hart, 2006, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting Vol(50), Issue 9*, p. 909 (https://doi.org/10.1177/154193120605000909). Copyright 2006 by Human Factors and Ergonomics Society.

The implementation of the NASA-TLX as a common subjective MWL assessment technique and has been applied successfully in many domains including civilian aircraft design, nursing, 3D immersive environments and many others (Hart, 2006; Tubbs-Cooley et al., 2018; Wang et al., 2021; Yiyauan et al., 2011).

Subjective Cognitive Load Testing's Impact Upon My Research

The intent of the research is to use ARCS principles as a starting point and Sweller's and Mayer's theories as a background for assessment. These theories play a critical role in the development of instructional materials and VRIPS software. NASA-TLX has a long history of providing useful research data regarding the mental stresses a participant is undergoing. Using this as a post treatment survey investigated the potential cognitive load issues surrounding VR based educational interventions.

Conclusion

This document presented a definition of terms used to describe the spectrum of virtual experiences and functionality available at the present time. A brief review of the state of XR technology market sector and challenges to XR adoption, lack of a killer app for the medium, were discussed. Along with brief discussion of several current successful XR applications including the author's views on the future of the XR medium. A presentation of immersive learning was detailed providing background knowledge pursuant to 3D virtual learning environment creation and the creation of instructional material leveraging XR technologies. In addition, opposing and supporting arguments for the inclusion of XR technology in the classroom were explored. Also included was a review of XR's utilization in education of abstract topics, a definition of VLE with opposing views about its level of success. Concluding with consideration of the professional implications of lifelong learning upon learner motivation and practical, current application XR learning to improve and extend patients quality of life.

An overview of the theoretical frameworks to be applied in this study was also explored. Beginning with an overview of constructivism, the founders, and recent innovators along with supporting and opposing views of the concept. The expansion of Mayer's (2014) theory of Multimedia Learning using Bodily-Kinesthetic Intelligence to explore support for a motion based modality was also discussed. In addition, the application of Keller's ARCS model applied as a pretext for the adult learning motivational impact was considered. Finally, the background and details of the NASA-

TLX Subjective Cognitive Load Testing instrument was investigated as part of the study's data collection and assessment strategy.

Chapter 3: Methods

"Life is a journey, not a destination" attributed to Ralph Waldo Emerson (O'Toole, 2012)

Overview

The research design detailed herein was implemented with a multi-pronged approach, intended to inform instructional designers about issues regarding Virtual Reality IP Network Subnetting education and the impact upon student learning experience as well as cognitive load issues during the learning process. The first section of the study sought to uncover the efficacy of using VR as part of instructional design for the education of IP Network Subnetting. This portion of the study was divided into two sub-parts, the first specifically investigates the student exploration of procedural knowledge (knowledge-how or knowledge built around skills/abilities). The second portion of the study analyzed cognitive load levels perceived by the participant while undergoing the treatment. The final inquiry explored the learning experience through thematic coding of semi-structured interviews with selected participants collected after treatment (L. Cohen et al., 2017). Integration of data from each section provided the researcher with a larger picture of the issues in VR education that affect student learning and instructional design.

The study employed a quasi-experimental design using a pre-test/post-test (L. Cohen et al., 2017; Salkind, 2010), thus allowing a statistical comparison of the median and mean differences between a control group (CG) and the experimental group (EG) (Cook & Campbell, 1986; Lewis-Beck et al., 2004). Semi-structured interview data with survey data related to cognitive load issues (Hart, 2006) provided a larger perspective identifying educationally limiting themes (Creswell & Creswell, 2018).

Participants were recruited from a subject pool of a public midwestern public university in the United States. The following sections detail Research Questions, choice of Virtual Reality IP Subnetting (VRIPS) software, selection of participants, data collection methods and data analysis. Additional details concerning the selection of participants is provided below.

The Virtual Reality IP Subnetting (VRIPS) Game

The researcher searched for existing digital game-based learning (DGBL) literature and commercial and educational software markets for software that accurately scaffolds the mental model needed to provide deep learning of IP Network Subnetting. Several packages that provide IP Subnetting were identified: Cisco Binary Game (*Cisco Binary Game*, n.d.) a game that creates scaffolding for IP Subnetting through the gamification of binary number conversion (essential in the binary IP subnetting method of learning), IPv4 Subnetting Practice (*Ipv4 Subnetting Practice*, n.d.) and SubnettingPractice.com (*SubnettingPractice.Com*, n.d.) provide a web-based interface for a series of numeric IP subnetting problems for students to solve, Subnetting Practice (Android Software) (*Subnetting Practice, Android Application*, n.d.) an Android application for the numeric practice of IP Subnetting, Subnetting Practice Game (*Subnetting Practice Game*, n.d.) is a web-based game that scores, based on shortest time to answer five numeric IP subnetting questions. No software was found that provided any VR based learning for IP subnetting. Research by Merchant (2014) found that software created by the researcher provided higher learning gains (Merchant et al., 2014). Therefore, the researcher designed and created such a piece of software. Secondarily because previously existing tools had been designed either as a support for the binary math learning methods or primarily as a speed drill training tool, they provided little learning scaffolding for first-time learners of the topic.

Participant Selection

Creswell (2018) determines a population as a grouping of individuals with comparable features. Participants were selected from students at a midwestern United States university in Ohio. The student population is approximately 28,000 students, this includes 3,000 graduate students. The participant group was selected using convenience sampling (Patton, 2015; Teddlie & Tashakkori, 2009) based on interest and attendance in networking technology classes. Using a self-selection process of participation in courses such as: ITS 2010, ITS 2300, ITS 3100, ITS 3010, ITS 4750, ITS 5750, CS 4750 and CS 5750. These courses teach introductory IP networking as part of the larger major curriculum at the university. The introductory two-thousand level courses lay the networking groundwork for more complex and advanced topics and coursework in computer networking. The advanced four thousand and five thousand level classes contain a segment of students that have been exposed to this material previously. However, previous experience is not a prerequisite for the course. Thus, the four and five thousand level course review, from the beginning, the same concepts as the two thousand level course as it relates to IP subnetting to provide the needed background for all students that may not have had the material in previous courses. A review of available courses at the university indicates that these classes are the entirety of the population of courses and students at the institution that cover IP subnetting concepts during the time of the study.

Participants were recruited in-person during class by the researcher, after viewing the research study presentation that reviewed the research study summary and goals. Participant consent to participate in the study was obtained through accepting or declining the IRB consent form prior to starting the pre-test portion of the learning process. An example of the informed consent form can be seen in Appendix E. The researcher created a list of participants in Microsoft Excel, divided them randomly and evenly into Control Group and Experimental Group.

Individual Interviews

Post qualitative data analysis interview participants were selected by the researcher after reviewing pre-test to post-test change scores and NASA-TLX scores. Participants were selected based on outstanding or extreme scores in either or both qualitative tests. The results of the survey helped guide the tailoring of questions to delve into their personal experiences during the treatment.

The researcher emailed potential participants inviting them for follow-up personal interviews. The emails were personalized to the individual with a reminder that they would receive a $10 gift card for participating in the interview process. Nine emails were sent to potential interview participants. Eight participants responded that they would be willing to participate in one-on-one interviews. Individual time slots were scheduled for the following week with no overlapping or adjacent time slots so that participants would not feel rushed or monitored by other participants.

The researcher utilized Microsoft Outlook calendar service to schedule and set details, such as location and time. Participants received notifications about the meeting details. A small, eight person on-campus conference room was used to conduct the interviews. Audio recording was done at the time and later transcribed using a paid transcription service named Happy Scribe (Happy Scribe, 2022). Due to the technical nature of the topic and terms discussed in the interviews the researcher re-transcribed, proofread and corrected the transcribed text. Additional rounds of reading the transcribed interview text were used to code them.

Data Collection Methods

Participants in both groups were given two assessments during the intervention. The first is a diagnostic assessment (pre-test) was given to both CG and EG before the intervention is applied to evaluate the participants existing knowledge regarding IP subnetting. The second assessment (post-test) was given to both groups for the purpose of determining the knowledge acquired after intervention. This design provided the ability to compare differences between the CG (who are provided traditional learning methods, supported with paper and pencil exercises) and the members of EG (who are provided traditional learning methods, and supported via the VRIPS software). Post treatment use of the NASA-TLX survey instrument with both groups provided a measurement of the cognitive load upon the participants during treatment.

Data analysis of the quantitative portions of the data collected were utilized to narrow the possible interview participants to include those with outstanding scores either in Pre-Test to Post-Test changes or NASA-TLX scores.

The triangulation of pre-test/post-test data, NASA-TLX data and interview data was completed to reveal more understanding of the ways that VR instructional material should be designed to maximize deeper and/or less stressful learning.

Procedure

Phase One: A conjoined learning session(s) for both CG and EG provides both groups with the necessary descriptive knowledge needed to begin the mental scaffolding processing for knowledge retention. The treatment schedule for the blended learning sessions, VR training sessions, testing and interviews is provided in Appendix G. The demographic survey and pre-test were conducted on both CG and EG, facilitated via paper survey. Demographic survey can be seen in Appendix A and the pre-test can be seen in Appendix B. The blended knowledge presentation including question and answer period provided the basic structure for the learning material. Participants received training in the use of the NASA-TLX survey instrument.

Participants were divided into control and experimental groups as detailed during the participant selection process. Participants in the EG group engaged in VR training to become comfortable with the VR environment and controls. After VR training the EG used VRIPS software to engage in multiple IP Networking Subnetting practice exercises. The CG worked through the same exercises with paper and pencil as shown in Appendix H. Both CG and EG took the NASA-TLX self-assessment survey and moved on to the post-test. An example of the NASA-TLX can be seen in Appendix E. The post-test can be seen in Appendix C.

Phase Two: After analysis of quantitative data from Phase One data was complete selected participants were invited to individual interviews about their experiences. Stratification of Phase Two participants were based on high, average, or low performance on the pre-test and post-test analysis, or based on unusual values from the NASA-TLX results.

Phase Three: The semi-structured interviews were done to draw a deeper understanding of participant perspectives and experiences during the treatment. An example of the semi-structured interview questions can be seen in Appendix D.

Data Analysis

Data analysis was completed in three segments. In the first data analysis segment, pre-test and post-test data was formally hypothesis tested with an error of 5% level of significance and confidence level of 95% was considered. Paired t test and independent t test results for pre-test and post-test data were used to provide descriptive statistics for each set of groups: mean, number of participants, standard deviation, and standard error of the mean, range, minimum and maximum, kurtosis, skewness, and several others. These results allow the researcher to understand the context for measurement related to the population.

The second segment of the data analysis segment analyzed the NASA-TLX data to determine relative levels of cognitive load during the VR intervention. The NASA-TLX instrument is a subjective workload measure developed in the1970s to assess pilot and air traffic controller workload (Hart, 2006; Hart & Staveland, 1988). It uses six items on a twenty point scale (low = 1 through high = 20) that attempt to measure different aspects of mental workload: Mental Demand (MD), or the perceived amount of mental/perceptual effort required such as calculating, thinking or deciding; Physical Demand (PD) or the perceived amount of physical activity required such as controlling or locomotion; Temporal Demand (TD), or the perceived amount of pressure felt to complete tasks at a time rate; Performance (PE), or perceived success at completing assigned tasks; Effort (EF), perceived amount of difficulty one had to accomplish at a certain level of performance; Frustration (FR), a measure of the discouragement verses content while completing tasks. Overall workload (OW) is calculated though taking the non-weighted (raw) summed numeric score of the items and ranges from a minimum of 6 to a maximum of 120 (Hart, 2006; Hendy et al., 1993; Said et al., 2020).

Mann-Whiney U test analysis of the data collected from NASA-TLX provided descriptive statistics and results comparing ranked medians over multiple categories. The ranked median comparison between the two groups provided insight into type and depth of cognitive load issues surrounding both the CG and EG. The NASA-TLX scores the participant with six dimensions (or subscales) that are summed and used as a unidimensional NASA-TLX score. In this case raw NASA-TLX scores were used. The use of raw NASA-TLX scores is common practice of the original scale making it easier to use (Hart, 2006; Mansikka et al., 2019; Said et al., 2020).

In the third data analysis segment, interview data component analysis was conducted to validate and reduce the data. This followed Creswell and Creswell’s

(Creswell & Creswell, 2018) five part process for qualitative data analysis. Organize data, Review all data, Coding Data, Generate description and themes, and Represent description and themes. After reviewing all the data a selection of coding types were chosen that are most appropriate to the overall trend of the data (Saldana, 2015). This approach allowed for unforeseen themes and data trends to be evaluated. Finally, a discussion of recurring themes and potential future avenues for VRIPS.

Ethical Protection of Research Participants

The ethics of interactions between participants and researcher was carefully considered. Several ethical codes have been created to guide and provide principles to address ethical dilemmas, for example, the U.S. Department of Health and Human Services 45 CFR (*United States of America, Code of Federal Regulations, 45 CFR 46 FAQs*, n.d.). These codes are created not only to assure that researchers consider ethical issues related to research, but also to give guidance when designing and conducting research. They are primarily focused upon protecting the research participant from harm (Sieber & Stanley, 1988).

The two most critical pieces of protection for both the participant and researcher are: informed consent and the institutional review board (IRB) (Marczyk et al., 2005). Informed consent, see Appendix F, is used to illustrate the purpose of the study, and any divulge involved. This is especially true if the study encompasses any issues of a sensitive nature. Third-party oversight in the form of institutional review boards (IRBs) provide additional oversight to limit potential harm that might befall the participant(s). Researchers submit a consent form for IRB committee review.

Research often collects a large amount of data about participants' private lives and community. Thoughtful consideration about protection and data handling should be detailed and carefully followed to protect participants from possible harm (Creswell & Poth, 2018). For this research, no monetary compensation was offered to participants. Further, it must be considered that participants were engaged in the research as part of a larger class structure.

Currently, all in-person research requires COVID-19 precautions, restrictions, and approvals. These restrictions are an ever changing landscape in an attempt to keep both participants and researchers safe (*Human Subjects (Irb) | Ohio University*, n.d.). This research took place in September of 2022 and followed all appropriate Ohio University and IRB safety guidelines. In August of 2022 the researcher gained IRB approval for this study, see Appendix I.

Validity

Messick (1986) states that validity is, "validity is an inductive summary of both the adequacy of existing evidence for and the appropriateness of potential consequences of test interpretation and use" (Messick, 1986, p. 2). While threats to validity cannot be erased completely, they can be recognized and addressed. In addition, Cohen (2017) states, "Reliability is a necessary but insufficient condition for validity in research; it is a necessary precondition of validity" (Cohen et al., 2017, p. 245).

Shadish (2002) identifies four primary types of validity: Internal, External, Construct, and Statistical Conclusion. Construct and external validity primarily concern generalization of data to a larger group.

Internal validity refers to the extent to which a study establishes a reliable cause-and-effect relationship between a treatment and an outcome. In a pre-test/post-test design experiment, there are several factors that could affect internal validity, including: Instrumentation, Testing, History, Maturation, Statistical Regression, Research Reactivity, Selection Biases, and Attrition (Crano et al., 2014, p. 32).

To control these factors' random number assignment was used to divide individuals into two groups (CG and EG). To avoid issues of environmental fluctuation both groups carried out the learning in the same environment and conditions, using the same facilities and faculty, viewing the same presentation and materials and having the same in-person classes. To minimize any instrumentation effect the pre-test and post-test were identical.

It is not possible to completely remove all threats to internal validity as both groups (CG and EG) attended the same Midwestern university. It is possible that a situation allowing for diffusion of treatments could have occurred. In the EG group it is also not possible to exclude the presence of a maturity effect, the students could have solved additional IP Networking Subnetting problems during or outside the intervention time frame which could provide deeper learning before the post-test.

External validity relates to issues that could limit the generalizability of the data. External validity is reduced in this context as the participant population was selected using convenience sampling from an educational setting and educational background. Conclusions drawn from this experiment address relevant details about the application to a larger population group.

A pilot test was carried out before the experiment to enable the researcher to adjust the learning materials, VRIPS software and evaluation instruments. To avoid the learning effect the pre-test and post-test instruments were identical. Conclusion validity was addressed with tests for normality and homoscedasticity carried out before the *t* test and the pre-test and post-test to avoid complications on reliability in the statistical analysis. An error of 5% level of significance and confidence level of 95% was considered while performing all statistical tests.

Construct validity in mixed method research is difficult to control as the quantitative data in this case was recorded directly from the participant. While the semi-structured interview data has been interpreted by the researcher and participants were selected by the researcher. Each of these issues make the result more susceptible to researcher bias.

NASA-TLX is one of the most frequently used measures of self-assessed cognitive workload and has been in use for over 30 years. The instrument has been used as a benchmark in many other pieces of research (Hart, 2006). The use of an established instrument for measuring cognitive load also provides many other researchers to test both its reliability and validity as an instrument. Devos's 2020 study on the psychometric properties of the NASA-TLX stated that the instrument as a, "subjective self-recall of cognitive workload is reliable" (Devos et al., 2020, p. 9). While several other study results found the NASA-TLX to be a valid instrument to measure mental and physical workload during the execution of tasks (Braarud, 2021, p. 10; Hart & Staveland, 1988, p. 38; Ruiz-Rabelo et al., 2015, p. 2456; Said et al., 2020, p. 9)

Several issues were revealed as methodological problems Hart (2006) points out is of context effect, where the TLX rating of one task may be significantly impacted by different experiences directly beforehand. Issues of range effect, wherein the rater does not use the entire range of the scale, were also shown to be problematic with the return of valid data.

Chapter 4: Results

"Genius is 1% inspiration and 99% perspiration." misattributed to Thomas Edison, correct attribution to Kate Sanborn (Ziegler, 2014)

Purpose

The purpose of the study was to explore how a VR educational tool can enhance basic IP subnetting learning outcomes in higher education. Three primary research questions are posed.

RQ1: How do participants' scores change from pre-test to post-test?

RQ2: What are the effects of VRIPS software on participant cognitive load as measured by the NASA-TLX subjective workload assessment instrument?

RQ3: What insights do the qualitative findings provide to help us understand the nature of the experiment and its results?

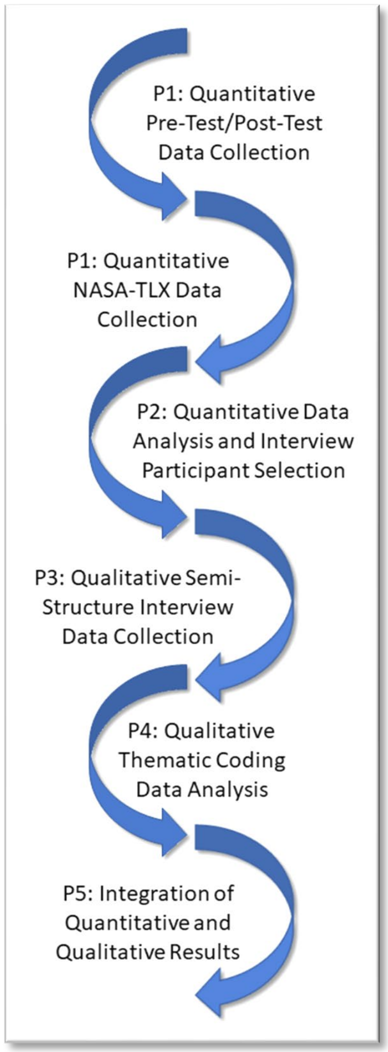
To gain understanding of these questions an explanatory mixed methods research approach that integrates quantitative and qualitative sources of data and analysis in a progression of data collection and analytic stages (Creswell & Plano Clark, 2018) was implemented. This process allows the qualitative sources to provide insight on the quantitative data.

Summary of Data Analysis Process

The first phase of the project consisted of the collection of quantitative data in the forms of pre-test and post-test IP subnetting scores and NASA-TLX scores. During the second phase the qualitative data collected was analyzed to identify interview participants. Phase three collected qualitative semi-structured interview data from the participants. Phase four the interview data is thematically coded for recurring concepts. Phase Five integrates the quantitative pre-test and post-test and NASA TLX results with the qualitative data taken from semi-structured interviews. Connection of quantitative results with qualitative data to provide summative results that help to explain the quantitative results using information from the participants who can most accurately articulate upon the quantitative results. The Figure 26 below provides a flow chart of the data collection and analysis process.

Figure 26

Explanatory Mixed Methods Research Process



Demographic Data

The participants were twenty-eight undergraduates from a midwestern United States university in Ohio drawn from two undergraduate classes in IP Networking: ITS 2300 and ITS 4750. The combined sample was primarily white males (25) with an average age of 21 years old. The participants were primarily ITS majors or double majors

(82.2%), Computer Science (14.3%), Business (3.6%). GPA for participants ranged from 2.0 to 4.0 with the mean at 3.22 GPA for all twenty-three participants that provided GPA data. Four participants indicated that they had no previous collegiate hours; the sample mean was 50.5 college level hours completed. The ITS 2300 participants indicated they had less experience with IP networking. While the ITS 4750 participants stated they had more experience with IP Networking.

Table 1

Basic Demographic Information

Categories	N	Percent	Categories	N	Value/Percent
Gender identity			Course		
Male	25	89.2%	ITS 2300	20	71.4%
Female	3	10.8%	ITS 4750	8	28.6%
Age			Major		
18-19	9	32.2%	ITS or ITS Double Major	23	82.1%
20-21	10	35.7%	Computer Science	4	14.3%
22-23	5	17.8%	Business	1	3.6%
24+	4	14.3%			
			GPA		
Ethnicity			ITS 2300	17	2.89
Asian	1	3.5%	ITS 4750	8	3.11
Black	1	3.5%	Total Reporting	23	3.22
Latino	1	3.5%			
White	25	89.5%	Mean Collegiate Hours Completed		
			ITS 2300	20	36
			ITS 4750	8	86.25
			Total	28	50.5

Previous IP experience was self-assessed on a five-point scale to gain background information regarding previous topical familiarity as shown below.

Table 2

Previous IP Experience

Categories	N	All Participants	N	ITS 2300	N	ITS 4750
Previous IP Experience						
Not at All	8	28.6%	8	40.00%		
Slightly Familiar	6	21.4%	6	30.00%		
Somewhat Familiar	3	10.7%	1	5.00%	2	25.0%
Moderately Familiar	10	35.7%	4	20.00%	6	75.0%
Extremely Familiar	1	3.6%	1	5.00%		

Previous VR experience was self-assessed on a five-point scale to gain background information regarding previous equipment and environmental familiarity as shown in Table 3.

Table 3

Previous VR Experience

Categories	N	All Participants	N	ITS 2300	N	ITS 4750
Previous IP Experience						
Not at All	5	17.9%	5	25.00%		
Slightly Familiar	6	21.4%	2	10.00%	4	50.0%
Somewhat Familiar	6	21.4%	5	25.00%	1	12.5%
Moderately Familiar	4	14.3%	4	20.00%	3	37.5%
Extremely Familiar	7	25.0%	4	20.00%		

Descriptive Statistics

Pre-Test and Post-Test

The following figures display pre-test and post-test scores descriptive statistics providing the Mean, Median, Mode, and trends providing context as to how the sample would represent to the larger population it was drawn from. Additional detail is available, in table format, in Appendix M.

Figure 27

Pre-Test and Post Test Score Averages

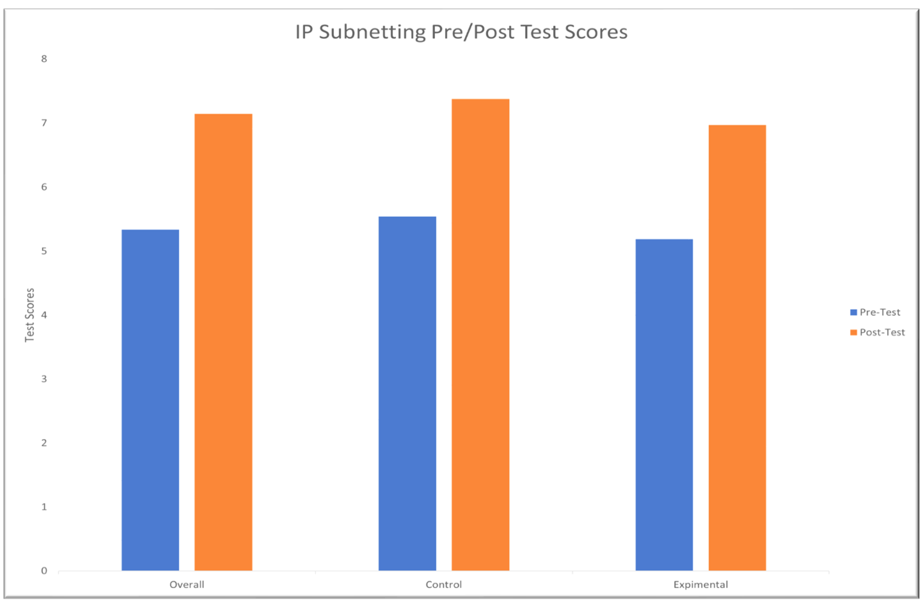
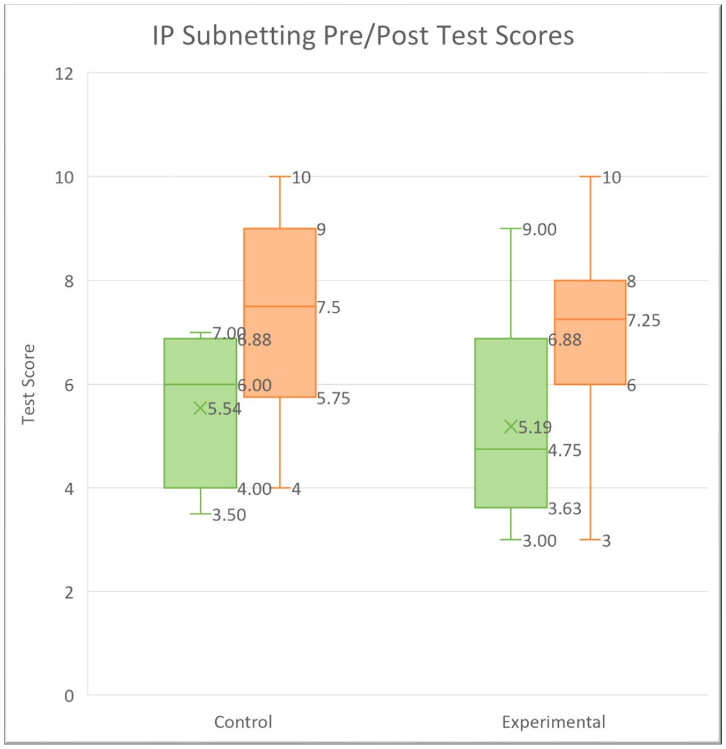


Figure 28

Pre-Test and Post Test Score Averages - Boxplot



NASA-TLX Descriptive Statistics

The following table provides the descriptive statistics for the NASA-TLX scores for all participants by treatment group and total.

Table 4

NASA-TLX Descriptive Statistics

Category / Treatment	Overall N	Overall Mean	Overall Mdn	Overall SD	ITS 2300 N	ITS 2300 Mean	ITS 2300 Mdn	ITS 2300 SD	ITS 4750 N	ITS 4750 Mean	ITS 4750 Mdn	ITS 4750 SD
Mental												
Control	12	13.25	15.00	4.86	8	13.38	14.50	5.50	4	13.00	15.00	4.00
Experiment	16	9.19	8.50	4.45	12	8.92	8.50	4.66	4	10.00	10.50	4.24
Total	28	10.93	11.00	4.98	20	10.70	10.00	5.36	8	11.50	13.50	4.14
Physical												
Control	12	4.50	2.00	5.21	8	5.50	3.50	5.58	4	2.50	0.50	4.36
Experiment	16	5.00	3.50	4.03	12	4.83	3.50	4.06	4	5.50	4.00	4.51
Total	28	4.79	3.00	4.49	20	5.10	3.50	4.60	8	4.00	2.50	4.41
Temporal												
Control	12	9.92	10.00	5.20	8	9.00	9.00	4.50	4	11.75	13.50	6.70
Experiment	16	5.69	4.50	4.29	12	4.67	4.00	3.82	4	8.75	9.50	4.46
Total	28	7.50	6.00	5.07	20	6.40	5.50	4.55	8	10.25	11.00	5.57
Performance												
Control	12	10.42	10.00	3.66	8	9.25	9.00	3.81	4	12.75	13.00	2.06
Experiment	16	8.44	7.00	3.98	12	7.92	7.00	4.08	4	10.00	10.50	3.74
Total	28	9.29	9.00	3.91	20	8.45	7.00	3.93	8	11.38	12.00	3.16
Effort												
Control	12	13.25	13.00	4.05	8	13.63	12.50	3.66	4	12.50	14.00	5.26
Experiment	16	8.50	8.50	4.16	12	4.78	7.50	4.28	4	11.50	11.00	1.92
Total	28	10.54	10.00	4.69	20	9.95	9.50	5.00	8	12.00	12.50	3.70
Frustration												
Control	12	13.00	14.00	4.63	8	12.13	13.00	4.73	4	14.75	15.00	4.50
Experiment	16	5.63	4.50	4.10	12	6.25	6.00	4.50	4	3.75	4.50	1.89
Total	28	8.79	8.50	5.65	20	8.60	9.00	5.36	8	9.25	7.00	6.69
Total												
Control	12	60.33	59.00	23.31	12	62.88	59.00	21.20	12	55.25	57.50	35.35
Experiment	16	42.44	40.00	16.17	16	40.08	35.00	17.72	16	49.50	49.00	8.19
Total	28	50.11	45.50	22.08	28	49.20	45.00	21.88	28	52.38	49.00	23.95

Research Question 1

RQ1: How do participants' scores change from pre-test to post-test?

Paired t test results comparing pre-test and post-test scores indicate that the learning process has a large and significant improvement in IP subnetting scores across all groups ($t(27)=-9.03$, $p=<.001$), with a large effect size (95% CI [-2.21, -1.39] Hedges's $g_s=1.09$). A paired t test was conducted to compare the IP subnetting test score results before and after treatment to determine significance. As a result of smaller sample sizes, Hedge's g was used to determine effect size (Hedges, 1981, p. 112; Hedges & Olkin, 1985) rather than Cohen's d which is included for completeness. Cohen offers a commonly used benchmark with reference to interpreting effect sizes: small (d => 0.2), medium (d => 0.5), and large (d => 0.8) (J. Cohen, 1988, p. 24). Hedges indicates that these same basic benchmarks should be used when interpreting Hedge's g results (Hedges, 1981; Hedges & Olkin, 1985). Due to the novel nature of the research and area of inquiry the literature review did not provide a benchmark that would be more appropriate for this area of study to provide more accurate effect sizes. However, in 2017, Richard E. Mayer, respected author of the Multimedia principle, used these Cohen's D benchmarks for his research on e-learning environments (Mayer, 2017).

The results from the combined pre-test (M=5.34, SD=1.6) and post-test (M=7.143, SD=1.84) of IP subnetting indicates educational the process produced an significant improvement in IP subnetting scores (t(27)=-9.03, p=<.001), with a large effect size (95% CI [-2.21, -1.39] Hedges's g_s=1.09).

The results from the Experimental pre-test (M=5.19, SD=1.76) and Experimental post-test (M=6.969, SD=1.87) IP subnetting tests indicate that the treatment including the VRIPS application resulted in an significant improvement in IP subnetting scores (t(15)=-6.25, p=<.001) , with a large effect size (95% CI [-2.39,-1.17] Hedges's g_s=1.2). A more detailed breakdown of the paired t test results is provided in Appendix L.

Deeper exploration of the results to understand if the VRIPS treatment was more effective at providing deeper learning of IP subnetting required the creation of a change score variable from the data. The Change Score is defined as a subtraction of the pre-test score from the post-test score. Comparing the means of the Change Score between the two groups provides perspective regarding the level of learning between control and experimental. An independent-samples t-test was conducted upon the Change Score to test means between Control and Experimental groups. Results of the t-test showed a no significant difference in the mean score for the two groups at $\alpha=.05$ level $t(26)=0.127$, $p<0.9$, two tailed. This result does not support the hypothesis that students in the experimental group who received the VRIPS treatment showed deeper depths of learning, as measured by the overall difference of pre-test and post-test scores, than the control group.

Figure 29

Test Score Averages by Class

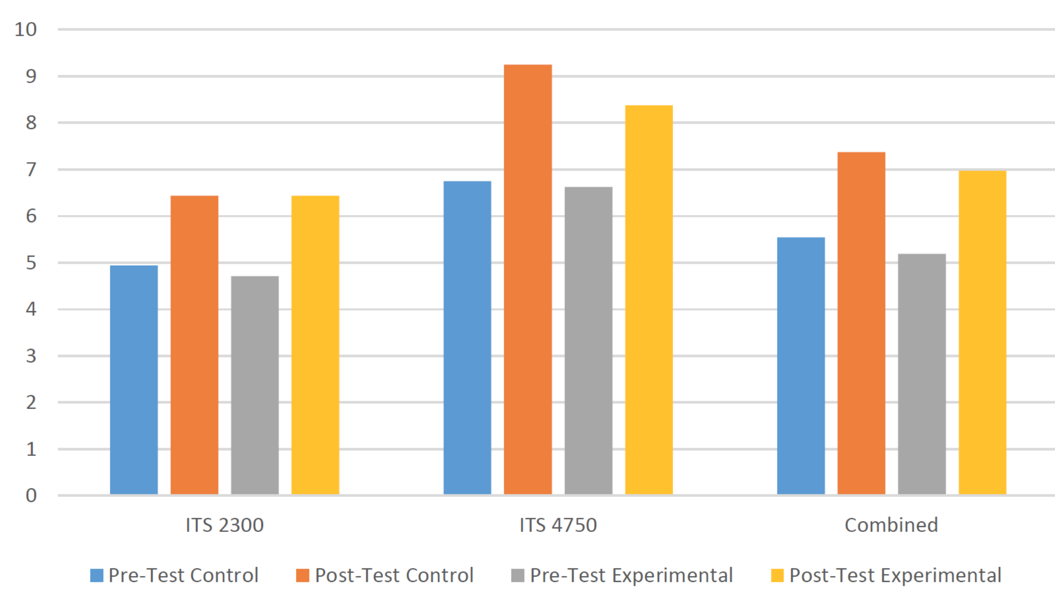


Table 5

Paired T Test Results - Test Scores

		N	M	SD	t	df	p	Hedges's g
All Cases								
	Pre-Test	28	5.339	1.599	-9.028	27	<.001	1.088
	Post-Test	28	7.143	1.835				
Control								
	Pre-Test	12	5.542	1.406	-6.449	11	<.001	1.059
	Post-Test	12	7.375	1.848				
Experimental								
	Pre-Test	16	5.188	1.760	-6.252	15	<.001	1.201
	Post-Test	16	6.969	1.866				

For expanded table see Appendix L

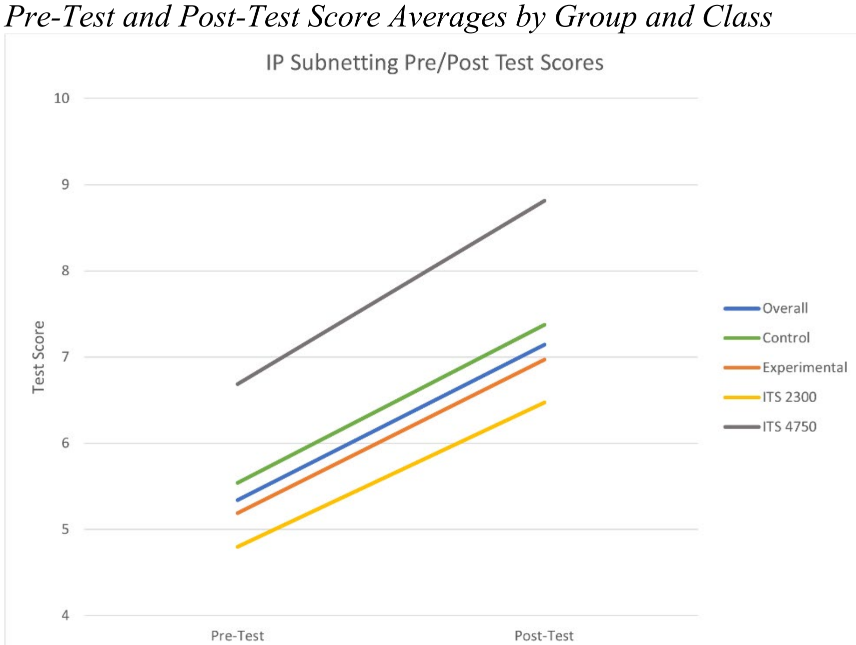
Change Score T Test Results

A paired sample t test was used to compare the difference of pre-test and post-test scores between participants divided into All, ITS 2300 and ITS 4750 as defined in Control (n=12) and participants defined as Experimental (n=16). As a result of smaller sample sizes, Hedge's g was used to determine effect size (Hedges, 1981, p. 112; Hedges & Olkin, 1985) rather than Cohen's d which is included for completeness. Cohen (1988, p. 24) offers a commonly used benchmark with reference to interpreting effect sizes: small (d => 0.2), medium (d => 0.5), and large (d => 0.8). Hedges indicates that these same basic benchmarks should be used when interpreting Hedge's g results (Hedges, 1981; Hedges & Olkin, 1985). Due to the novel nature of the research and area of inquiry the Virtual Reality in education literature review did not provide a benchmark that would be more appropriate for this area of study to provide more accurate effect sizes. Richard E. Mayer, respected author of the Multimedia principle, used these Cohen's D benchmarks for his research on e-learning environments (Mayer, 2017).

The figure displayed below provides a graph of the t tests by course with ITS 2300 Control (n=8) and Experimental (n=12) and ITS 4750 Control (n=4) and Experimental (n=4). A Shapiro-Wilk test did not show evidence of non-normality in either the Control group (W(12)=.873, p=0.071) or Experimental group (W(16)=.961, p=0.688). A Levene's test was found to be non-significant (F(1,26)=1.369, p=0.253), so equal variances were assumed. There was a no significant difference in the scores in the pre-test to post-test in Control group (M=1.833, SD=.984) and Experimental group (M=1.78, SD=1.14); t(26)=.127, p<0.9, two tailed. Table 7 shows the results of the paired t tests and by course. Additional detail is available, in table format, in Appendix J.

Figure 30

Pre-Test and Post-Test Score Averages by Group and Class



Research Question 2

RQ2: What are the effects of VRIPS software on participant cognitive load as measured by the NASA-TLX subjective workload assessment instrument?

Mann-Whitney U tests were used to compare the six NASA-TLX scores and the combined raw score between participants defined as Control (n=12) and participants defined as Experimental (n=16). The Mann-Whitney U Test was selected in place of an independent t test because of the nonparametric nature of the data. Effect size was determined using the Z statistic generated in Microsoft Excel to produce an *r* value, calculated in using the following formula $r = Z/\sqrt{N}$ (Hedges & Olkin, 1985). As a result of smaller sample sizes, Hedge's g was used to determine effect size (Hedges, 1981, p. 112; Hedges & Olkin, 1985) rather than Cohen's d which is included for completeness. Cohen (J. Cohen, 1988, p. 24) offers a commonly used benchmark with reference to interpreting effect sizes: small (d => 0.2), medium (d => 0.5), and large (d => 0.8). Hedges indicates that these same basic benchmarks should be used when interpreting Hedge's g results (Hedges, 1981; Hedges & Olkin, 1985). Due to the novel nature of the research and area of inquiry the literature review did not provide a benchmark that would be more appropriate for this area of study to provide more accurate effect sizes.

Table 8 below provides a breakdown of Mann-Whitney U test score by category and course with ITS 2300 Control (n=8) and Experimental (n=12) and ITS 4750 Control (n=4) and Experimental (n=4). A Shapiro-Wilk test did not provide evidence of normality in the Physical ($W(28)=.857$, $p=0.001$) or Temporal ($W(28)=.907$, $p=0.017$) categories. A Levene's test was found to be nonsignificant in all categories Mental ($F(1,26)=.023$, p=.881), Physical (F(1,26) =.020, p=.888), Temporal (F(1,26) =.0742, p=.397), Performance (F(1,26) =.643, p=.430), Effort (F(1,26) =.183, p=.673), Frustration (F(1,26) =.012, p=.913) and NASA-TLX Raw (F(1,26) =.112, p=.740) so equal variances were assumed.

The Mental activity of the CG and EG were compared using a Mann-Whitney U test. On average the CG (Mdn=15) reported higher activity than the EG (Mdn=8.5) also showing statistically significant results, U(NControl=12, NExperimental=16)=49.5, z=-2.16, p=.029, r=.409. The difference in Mental activity between CG and EG is statistically significant.

The Physical activity of the CG and EG were compared. On average the CG (Mdn=2.0) reported less activity than the EG (Mdn=3.5). A Mann-Whitney U test indicated that this difference was not statistically significant, U(NControl=12, NExperimental=16)=74.5, z=-1.01, p=0.324, r=0.190. The difference in Physical activity between CG and EG are not statistically significant.

The Temporal demand of the CG and EG were compared. On average the CG (Mdn=9.00) reported higher demand than the EG (Mdn=5.5) A Mann-Whitney U test indicated that this difference was statistically significant, U(NControl=12, NExperimental=16)=48.8, z=-2.214, p=0.418, r=0.418. The difference in Temporal demand between CG and EG is statistically significant.

The Performance satisfaction of the CG and EG were compared. On average the CG (Mdn=10.0) reported higher satisfaction than the EG (Mdn=7.0). A Mann-Whitney U test indicated that this difference was not statistically significant, U(NControl=12, NExperimental=16)=71.0, z=-1.169, p=0.026, r=0.221. The difference in Performance satisfaction between CG and EG is statistically significant. The Effort levels of the CG and EG were compared. On average the CG (Mdn=13.00) reported higher levels than the EG (Mdn=8.5) A Mann-Whitney U test indicated that this difference was statistically significant, U(NControl=12, NExperimental=16)= 38, z=-2.702, p=0.006, r=0.511. The difference in Effort levels between CG and EG is statistically significant.

The Frustration levels of the CG and EG were compared. On average the CG (Mdn=14.00) reported higher levels than the EG (Mdn=4.5) A Mann-Whitney U test indicated that this difference was statistically significant, U(NControl=12, NExperimental=16)=24.5, z=-3.333, p<.001, r=0.630. The difference in Frustration levels between CG and EG is statistically significant.

The NASA-TLX Raw scores of the CG and EG were compared. On average the CG (Mdn=59.00) reported higher levels than the EG (Mdn=40.00) A Mann-Whitney U test indicated that this difference was statistically significant, U(NControl=12, NExperimental=16)=52.5, z=-2.021, p=0.042, r=0.382. The difference in NASA-TLX Raw scores between CG and EG is statistically significant.

Table 6

NASA-TLX Results

	N	U	Exact Sig.	r
All Cases				
Mental	28	49.5	0.03	0.409
Physical	28	74.5	0.32	0.190
Temporal	28	48.8	0.03	0.418
Performance	28	71.0	0.26	0.221
Effort	28	38.0	0.01	0.511
Frustration	28	24.5	< .001	0.630
Total	28	52.5	0.04	0.382
ITS 2300				
Mental	20	24.0	.069	0.415
Physical	20	47.0	.970	0.017
Temporal	20	19.0	.025	0.504
Performance	20	39.5	.521	0.148
Effort	20	11.0	.003	0.640
Frustration	20	17.0	.016	0.539
Total	20	17.0	.016	0.535
ITS 4750				
Mental	8	3.0	.200	.523
Physical	8	3.0	.200	.513
Temporal	8	5.5	.486	.258
Performance	8	4.5	.343	.362
Effort	8	5.0	.486	.308
Frustration	8	0.0	.290	.826
Total	8	8.0	1.000	.000

For expanded table see Appendix K

NASA-TLX Results Graphical Representation

The following radar plots (Figures 31-33) and boxplots (Figures 34-40) provide a visual representation of NASA-TLX data to allow for an easier understanding of the relationships occurring. Radar plots show the means for each group and categories.

Boxplots provide visual representation of mean, median and range for each category and group.

Figure 31

VRIPS – All Participants NASA-TLX

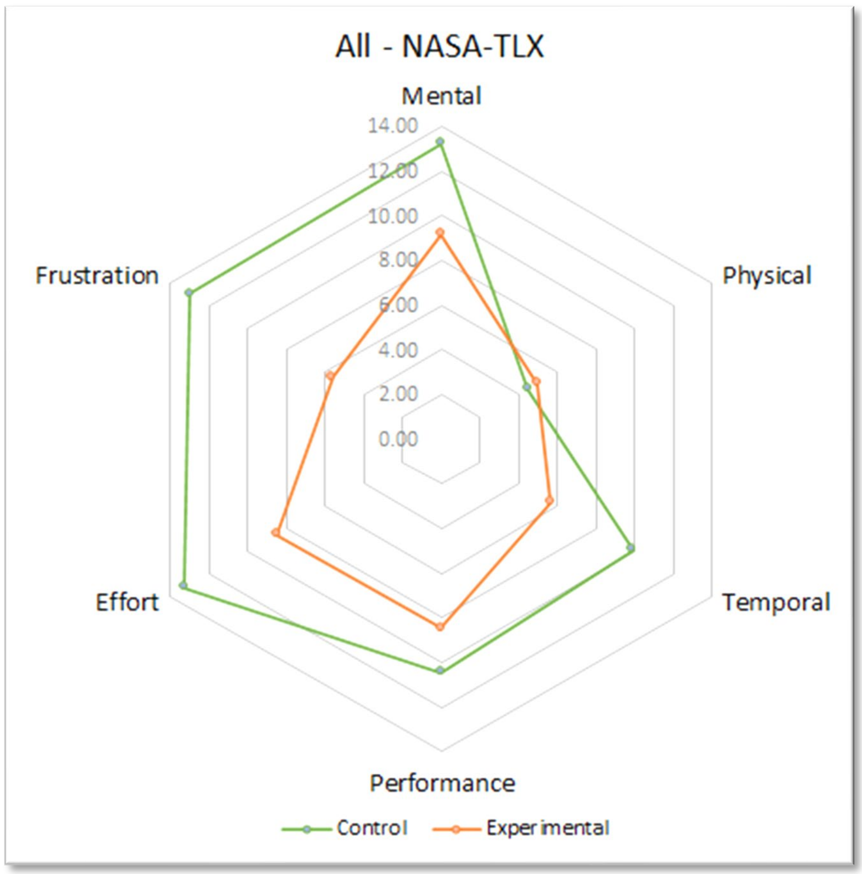


Figure 32

VRIPS – ITS 2300 – NASA-TLX

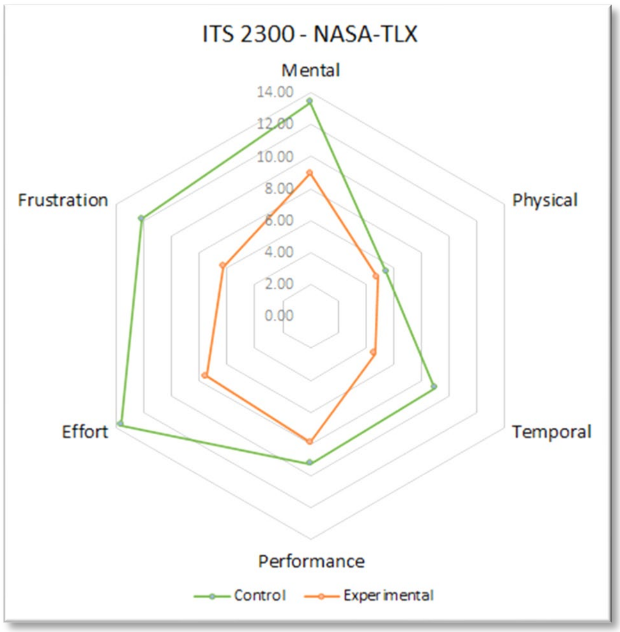


Figure 33

VRIPS – ITS 4750 – NASA-TLX

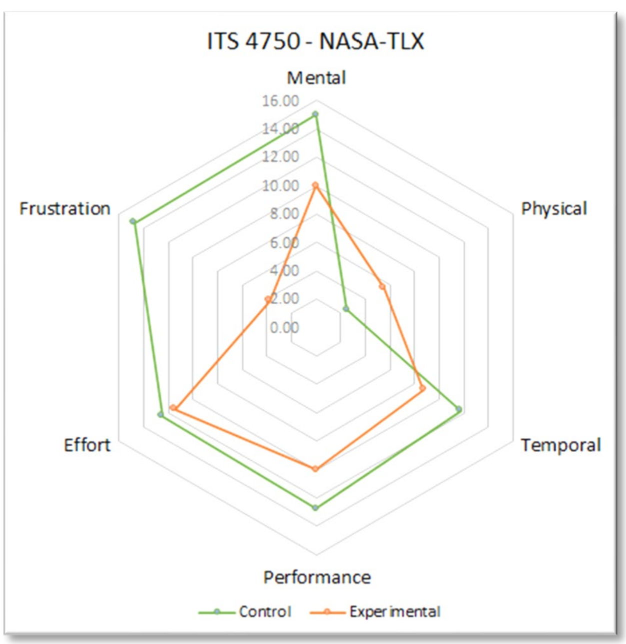


Figure 34

All - NASA-TLX - Mental

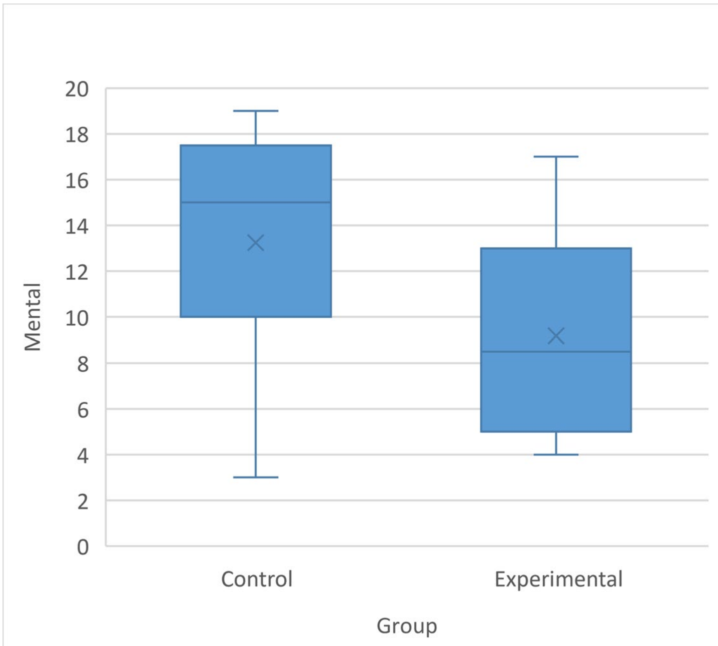


Figure 35

All - NASA-TLX - Physical

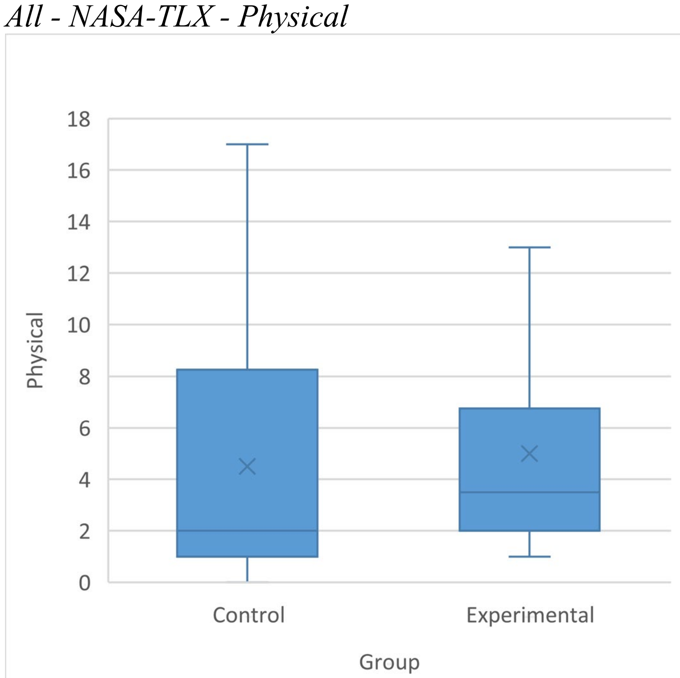


Figure 36

All - NASA-TLX - Temporal

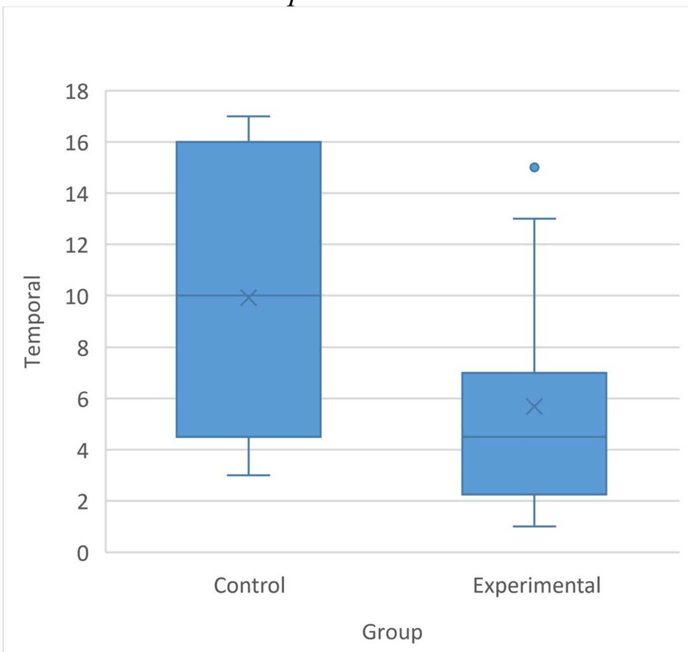


Figure 37

All - NASA-TLX - Performance

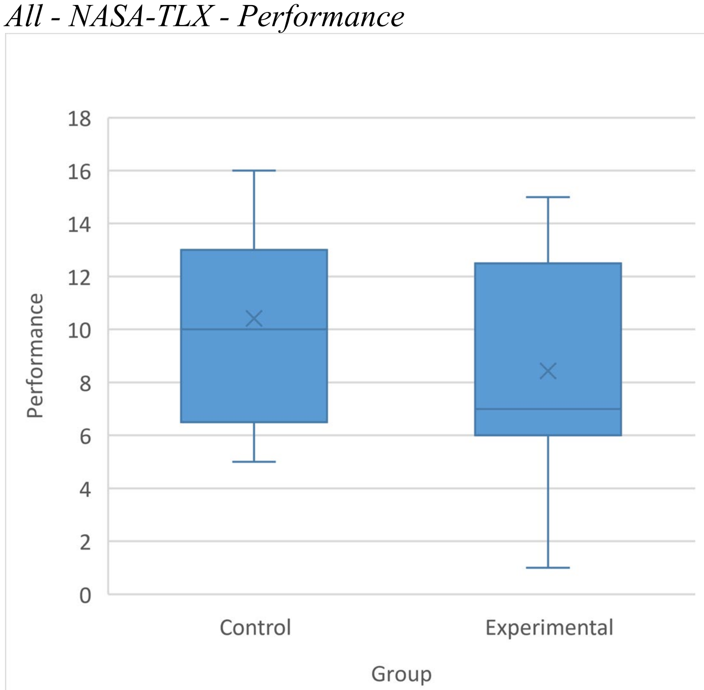


Figure 38

All - NASA-TLX - Effort

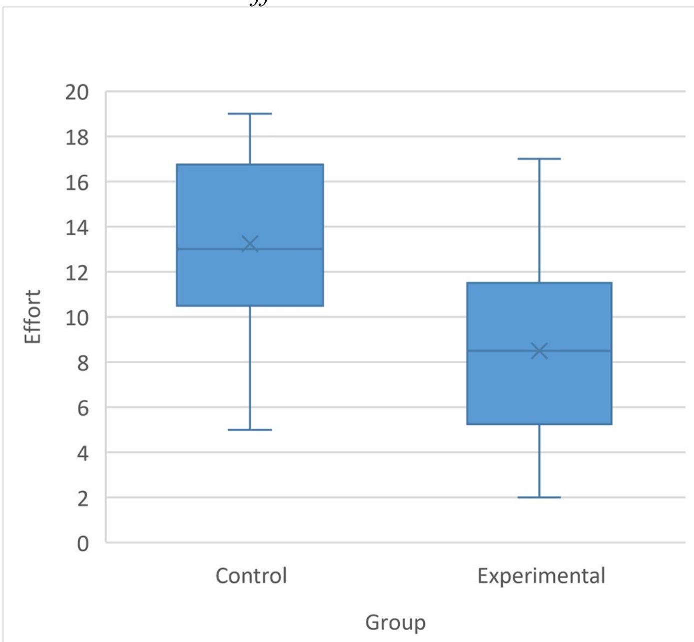


Figure 39

All - NASA-TLX - Frustration

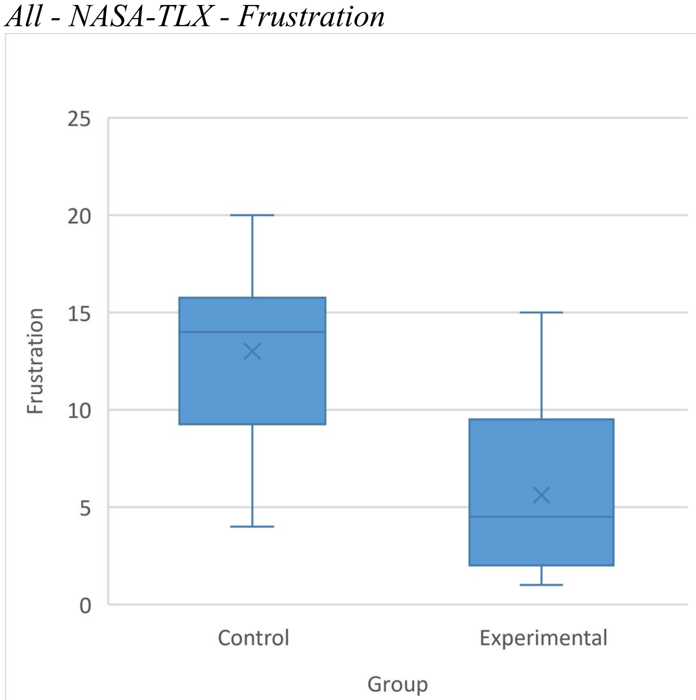
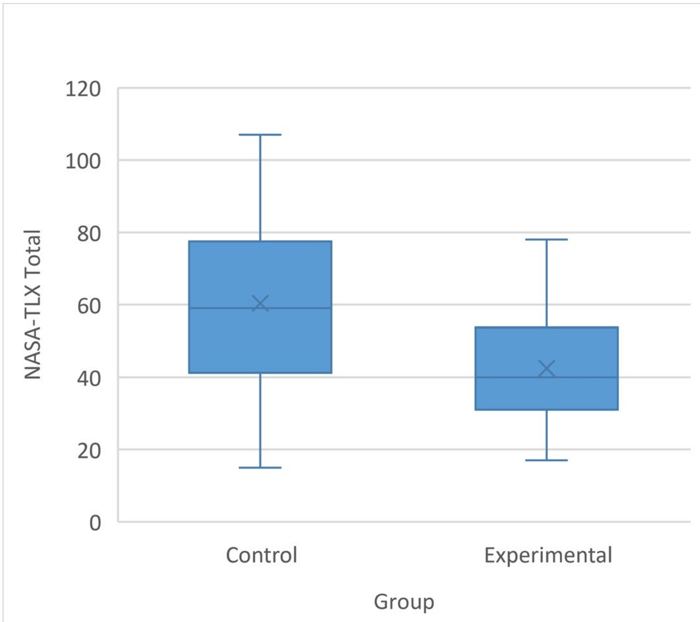


Figure 40

All - NASA-TLX -Total



Research Question 3

RQ3: What insights do the qualitative findings provide to help us understand the nature of the experiment and its results?

Demographic Stage Data

During the Demographic stage five of the eight participants interviewed (62.5%) indicated multiple previous VR experiences. However, no participants indicated that they had used VR for training in past learning experiences. Five of the eight participants interviewed (62.5%) indicated that they expected to use the IP subnetting as part of their future career.

Themes From Interview Data

Analyzing the data from the quantitative data collection process provided several experimental participants with interesting NASA-TLX scores to interview. Ten participants were invited for interviews and eight accepted. The interview participants were given a $10 gift card from either Amazon or Chipotle for their participation in the interview process. The interview process was broken down into four stages.

First, each participant was provided with a printed sheet showing their pre-test scores, post-test scores and NASA-TLX scores along with an overview of the averages of those same scores from the rest of the experimental group for context. A box plot of the pre-test scores and post-test scores for both control and experimental groups was provided. A radar plot of the six NASA-TLX scores showing control, experimental means and participant scores was also provided to the participant. During the first part of the interview this information was reviewed to provide the participants with a contextual understanding of their scores and to answer any questions. In addition, some basic demographic questions were asked.

Second, open-ended questions about the process the participant used to approach the VRIPS experience and problem-solving approach were asked. Questions such as, “Describe the process you used to solve the subnetting exercises?” and “When you started VRIPS what was the first object you saw in VR?”. These questions were designed to delve deeper into the participants’ perspective and understanding of the VRIPS environment and activities.

Third, open-ended questions were selected by the interviewer from a list pertaining to the participants’ NASA-TLX scoring. The interviewer prioritized questions that related to the participants' more extreme scores on the NASA-TLX. Questions such as, “Looking back on the VR experience, how did the time limits affect the completion of exercises?” and “Recalling your performance during the VR experience, describe your satisfaction level to accomplish the tasks set by the exercises?”.

Fourth, as the interview concluded, the interviewer asked open-ended questions related to the overall VR experience and allowed the participant to ask the interviewer any questions that they might have about the topics discussed at the interview. Questions such as, “While using the VR experience, describe what was most interesting or significant to you?” and “Do you have any questions or comments about any topics we discussed today?”.

Thematic coding of the interview data was done over a period of several rounds. Table 9 provided below shows the evolution of the coding by interview stage.

Table 7

Evolution of Codes and Coding Themes

	Second Coding Themes	**First Coding Themes**
Demographics	multiple VR experiences	
	no VR experiences	never really done anything before with VR
	multiple learning VR experiences	
	no learning VR experiences	
	future career	
	school requirement	needed an elective, wanted deeper understanding, further my education
VRIPS	*Object First Seen?*	
	network stick	subnetting strings, white block that you break, subnetting stick
	information boards	read the question, start looking at the subnet amounts
	cheat sheet	
	Problem Process	
	easy	easier to show subnetting, very self-explanatory, everything was very easy to do, easier to show the breakup of a network
	fun	really fun, enjoyable
	interactive	working with my hands
	gamification	check my score, look over and see my score
	immersive	different perspective, fully immersed
	spatial organization	
NASA-TLX	*Mental*	
	fun	
	easy	
	moderate	
	difficult	
	Physical	
	Physically easy to interact with VR environment	
	immersive	
	physically struggling with VR environment	break network stick accidentally, TOO immersive
	physically struggling with equipment	hot and sweaty, reach a little further, controller issues, blurry vision

VRIPS Stage Themes

Themes that arose during this line of inquiry indicated a wide range of indications and motivations related to the problem-solving process in a VR environment. Most participants started working with the “network stick” (VRIPS visual representation of an IP subnet) indicating they felt the process to be easier than working on paper. Statements such as: “It [VRIPS] was easy to use. So, I think it was more fun than just having a piece of paper and just subnetting on a piece of paper.” (P02) Several participants spoke about the interactive and spatial organizational aspect that a VR environment provided stating:

It was nice to be able to push away the smaller subnets. I could just focus on one of them. I could move it over on the side and just focus on the one largest subnet and then break that down until I've used all of it. And then, I don't know, it helped me compartmentalize what subnets were possible without having to get worried about all of the potential ones. (P08)

Just saying something and thinking about it in my mind is difficult, but actually doing it and having a physical aspect to it helps a lot, and I think it would help people that are more in the practical thinking than logical thinking aspect, but for me, it helped a great deal because I like working with my hands on hardware stuff and you can't really do that with software” (P04).

“VR was just kind of a way to, here it is in practice, here's a visual aid” (P05).

Participants were also stating that the immersive and interactivity qualities of the VR experience stating: “I do think it was visually seeing subnets and being able to break them into smaller pieces that are visually smaller. I think that helped differentiate in a way that you can't really do with an IP calculator" (P08).

> Probably the most significant thing was being fully immersed, even down to the sound effects that were being used. It made me feel like I was actually doing work instead of looking at a piece of paper and thinking about it and then just writing it and forgetting about it. I actually took what I can remember and applied it to the next step. (P04)

Change Score Testing Results

Reviewing the Change Score results indicates that the VRIPS treatment provides similar levels of learning of IP subnetting scores ($t(27)=-9.03$, $p=<.001$), with a large effect size (95% CI [-2.21, -1.39] Hedges's $g_s=1.09$). However, the Change Score results ($t(26)=.127$, $p<0.9$) suggest that VRIPS creates situational interest, but as has long been understood, the addition of novel modalities to learning material may not be enough to create an environment that encourages deeper learning (Dewey, 1913). While learners did not demonstrate deeper learning this could indicate VRIPS users were relieved of additional extraneous cognitive processing allowing the learners to learn more quickly or with less cognitive load during the learning process. When asked about how the VR experience was impactful,

It positively affected it because just saying something and thinking about it in my mind is difficult, but actually doing it and having a physical aspect to it helps a lot, and I think it would help people that are more in the practical thinking than logical thinking aspect, but for me, it helped a great deal because I like working with my hands on hardware stuff and you can't really do that with software. (P04)

Literature supporting that VR is useful in an educational context (Christopoulos et al., 2018, 2020; K.-T. Huang et al., 2019; Pellas et al., 2020), also states that its educational inclusion needs to be understood outside the laboratory in classroom and industry settings to fully explore the application of technology (Wolfartsberger, 2019).

The pre-test to post-test differential was not significant and therefore no interview participants were selected using that measurement. However, in other VR research utilizing pre-test and post-test score by Makransky noted, “if we had stopped our assessment with a retention test, as is commonly done in intervention research, we would have concluded that there was no academic advantage to learning in VR.” (Makransky et al., 2019, p. 10). Due to issues such as the ones Makransky references, additional avenues of data collection and analysis were pursued to offer additional perspectives on the central research issue.

NASA-TLX Stage Themes

Experimental participants completed the NASA-TLX self-assessment survey after the VRIPS treatment. The NASA-TLX stratification of categories makes it easier for participants to focus on the responses related to specific aspects of their experiences in VR. Some participants spoke about their physical struggles with the equipment or their physical struggle with the VR environment providing statements such as: “The controller felt a little big, and I've got itty bitty thumbs, and I'm also not used to that much my vision being that blurry” (P07).

I wasn't really used to all that physical movement and everything and not being able to see the outside world was very weird for me because I had to bend down and I didn't know if I was going to hit the floor or not for a lot of stuff. (P04)

"Sometimes I had to reach a little further to the right to get it in the right hole [scoring ring]" (P03).

The explanatory sequential mixed method research design used consists of examining the qualitative results from pre-test and post-test results and NASA-TLX results with qualitative interviews, exhibiting the results that link the quantitative results with the qualitative research questions, and interpreting the results to help explain the qualitative results with information from participants who can best reflect on the quantitative results. Several categories of the NASA-TLX provided statistically significant results with medium and large effect sizes in categories of Mental, Temporal, Effort and Frustration.

Mental. The mental activity reported by experimental participants was considerably lower than that reported by participants in the control group. This suggests less mental activity is required due to the spatial organization of the problem set provided by the VRIPS software. Experimental participants recorded that significantly less mental activity ($p=.029$) was required to complete the VRIPS activity indicating that it was 16.72% easier to complete assignments. Participants stated,

It kind of makes it easier because you have everything all in one area, but you don't necessarily have to find it. It's pretty basic how you go through the process, and using the VR to split the strings, find the correct amounts, and then put them in the respective servers, and do them that way. So, I think it was a little bit easier just having everything kind of contained. (P03) “the way they [network sticks] broke and you could see them all” (P02) “Breaking up the network sticks. That's pretty neat. And it just helps you kind of understand the size of the network better. I guess when just breaking them up like that.” (P01)

Temporal. The overall scoring for temporal indicated that time pressures were less of a cognitive pressure for the experimental group. The time pressure recorded by Experimental participants was significantly less (p=.025), providing a 17.51% reduction in feelings of being rushed during the VRIPS process. Supporting the idea that learning in virtual spaces requires less cognitive overhead.

> There was plenty of time to go through it and actually work through it, figure stuff out, and still finish with plenty of time left over to go back if you wanted to do some more, practice a little bit more. So, the time was very, very good. (P03)
> “I felt comfortable taking my time” (P08).

Effort. Participants found the VR environment to require significantly less effort (p=.006), physical and mental, indicating a 26.07% reduction in the effort to accomplish the assignments during the VRIPS process. However, the participants interviewed provided more detail and were divided in their responses. Three groups of participant response themes emerged during data analysis. The first group of interview participants found the physical nature of the equipment required extra effort to accomplish the assignments. A second group indicated that the physical/virtual nature of the experience required additional effort to deal with while completing assignments. Matching the movements and perceptions of their physical world to interact with virtual objects required additional effort. The third group indicated that they had no issues with the environment, which is in accordance with the overall NASA-TLX results. This suggests that better in future research more demographic data should be recorded to explore the divisions uncovered. The first group, labeled effort/physical, made statements such as, “I'm five feet tall, and I've got little arms. And I fumbled the controller a couple of times and might have accidentally deleted question eight or something” (P07).

> I have a lot of hair so under the VR headset it's hot. It gets hot sometimes. And it makes me a little bit motion sickness if I'm there for too long. But that was probably a little frustrating and it makes me sweat a little bit too because it's pushing up against my forehead. (P02)

The second group, labeled effort/virtual, made statements indicating they required more effort to physically manipulate within the virtual environment or struggled with physical perception within the virtual environment,

> I wasn't really used to all that physical movement and everything and not being able to see the outside world was very weird for me because I had to bend down and I didn't know if I was going to hit the floor or not for a lot of stuff. (P04)

“Yeah, also kind of hard occasionally see where the indicator for when you're pointing your controller is” (P07).

The third group, labeled effort/both, indicated they had few issues, which was in line with the NASA-TLX data making statements such as, Like I said, this was the first time I've ever done VR. Everything was very smooth. Everything was very easy to do. Very easy to adapt to it and pick it up quickly. It's not something that took a long time to figure out or stuff like that. Got in two or three minutes of playing around, and kind of figured out what you were doing and how to do it. (P03)

Frustration. Overall participants found that the VRIPS learning environment was significantly less frustrating to work within the VR environment ($p<.001$). They indicated that it was 39.67% less frustrating than the VRIPS environment. Overall frustration scores indicate that time was not a huge cognitive load function. Details during the participant interview process indicate themes showing that though the learner had an additional learning curve from the VR environment they still had enough time to complete the assigned tasks without feeling pressured. This would support the idea that participants learned more quickly in VRIPS than by the traditional methods. Participants expressed a positive view of the VR environment stating, "I think the more you mess with it, get familiar with everything in the little world, I guess, it probably just makes it easier." (P01)

I kept accidentally breaking them [network sticks] in half or I would hit them against each other and I'd them mixed up and I have to flip it over and try and read it because they get backwards. And that just made me mad for some reason. But after I got used to the mobility and controls of the thing, it wasn't that bad. It was just at first when I just couldn't figure it out. (P02)

I think it was very easy to just separate the subnets in half and then not worry about all of the excess. It was very easy to get the subnets to the size that I wanted and then put them into the space where it was needed, and then just do that. (P08)

Overall Stage Themes

At the end of the interview, questions were asked to get a generalized overview of the process from the participants. These questions offered the participants a chance to provide any feedback or include any ideas that weren't covered in earlier questions. The environment was generally perceived to be easy to navigate and use while being engaging and educational. Eliciting statements such as,

I've never had or even heard anyone make an assignment, a schoolwork assignment in VR that actually played well and was still educational at the same time. I think that attracts a lot of people because people are just so tired of doing something on paper, just writing something. That's so unique and it's fascinating. (P02)

This was the first time I've ever done VR. Everything was very smooth. Everything was very easy to do. Very easy to adapt to it and pick it up quickly. It's not something that took a long time to figure out (P03)

I feel like it's difficult to learn everything distinctly from what you see on a whiteboard or a PowerPoint every day, in VR more immersive and more hands-on. So, I feel like there's that kind of memorability aspect to it. I feel like, if it was something that I did once a week, I would definitely remember what I did in VR. (P06)

Summary

This chapter provides results from data analysis of all three phases obtained during data collection. Research Question 1 investigated what changes would occur in the pre-test to post-test scores of the participants. The results provided by the study reveal that the learning process for both groups supported the necessary mental schema creation to meet IP subnetting learning objectives. Learners were able to effectively learn IP subnetting using the VRIPS software and from traditional methods. As VR technology becomes more prevalent the additional modalities of instruction allow learners to encounter concepts that are often completely virtual in a situation that can allow them to engage with the concepts across more modalities.

Research Question 2 explored NASA-TLX survey results to determine the level of cognitive load upon the learner during the learning process. Results indicate that in four of the six categories and overall raw score the VRIPS software put significantly less cognitive load upon the learner than traditional learning methods. VR technology can implement a modality that allows a less stressful interaction with subject matter. This can be especially helpful when the subject matter is typically non-physical or conceptual in nature. The lessening of cognitive load allows the learner to contemplate the material and construct mental scheme more quickly.

Research Question 3 considered additional information and perspectives that provided a deeper reflection of the learners VRIPS experience. After analyzing data collected for Research Question 1 and 2 the researcher invited participants to interview with a specific focus upon individual aspects of their experience. Interview participants gave specific highlights conjoining their use of VRIPS software and their IP subnetting learning experience. These statements included reports detailing the physical nature of equipment, the conflicting immersive qualities of VR between physical and virtual realities and the overall ease of use that the learner experienced while using the VRIPS software.

Chapter 5: Discussion and Conclusions

"Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do." Steve Jobs (Standford University, 2005)

Overview

This explanatory sequential mixed method research was undertaken at a Midwestern University to gain knowledge about the specific relationships between Virtual Reality learning environment and IP subnetting in a college level learner's context. A quasi-experimental pre-test/post-test, the NASA-TLX cognitive load self-assessment, and semi-structured interviews were used to examine this relationship in more detail. This chapter seeks to delve into the findings related to the three research questions. After which, the perspective shifts in such a way as to integrate the findings from the first two research questions combining it with the qualitative findings to gain a larger understanding and perspective for the third research question. The chapter concludes with a review of the study limitations and future directions for this research.

Change Score Discussion

The Change Score results reflect the entire learning process that both groups undertook. Those results provide knowledge that the learning process provided a significant learning benefit for all the participants in the subject of IP subnetting. Additional independent t tests which removed the more experienced students in ITS 4750 (n=8) removed also did not show any significance. However, with the more experienced students removed, viewing just the ITS 2300 students, reveals a positive effect and a trend towards significance $t(18)=-0.610$, $p<0.549$, two tailed. Which may indicate that the treatment would be more effective upon learners with less previous IP subnetting experience.

Mayer's Theory of Multimedia Learning (2014) states that multiple modalities help students' material learn more deeply. This study undertook the examination of that concept measuring learning outcomes on several scales. The learning process utilized several different modalities of learning: slides, lecture, small group activities, paper and pencil, video tutorials, interactive web sites and VR software (for the experimental group) to name a few. The pre-test to post-test Change Score data analysis indicates that the VRIPS treatment was just as effective as traditional learning methods. On the surface this does not appear to be a laudable achievement. This fact is worthy of mention because even though the VR environment, controls and software were new to the learner, the learner was still able to learn as much in a novel environment than in the typical learning environment.

This implies that deeper learning could be achieved through more familiarity with the VR ecosystem. Issues that hinder VR users' learning could be ameliorated through broader acceptance of VR technology, standardizing its controls and user interfaces. Mayer's model (Mayer, 2014, p. 83) defines transfer of sensory memory to working memory through the selection of images and words. Newer learners that are often unfamiliar with the haptic and sensory input struggle and are unable to leverage prior knowledge when sorting through the input to build an accurate mental schema as deeply or quickly as a learner that has already created and familiar haptic and sensory input pathways. As VR user challenges become sublimated as part of general use and familiarity it should free up cognitive overhead for deeper learning.

Cognitive Load Discussion

NASA-TLX scoring indicated significance in the overall score and in the case of four of six sub scores. This would imply that learning in VRIPS reduced the levels of intrinsic and extrinsic cognitive load as defined by Sweller (1994). Sweller states that intrinsic cognitive load arises from the number of interrelated elements needed for learning. Scores and statements from participants indicate that they needed to track fewer mental elements as they were represented visually in VRIPS. Raja et al. (2004) indicated that students need multiple experiential levels to learn, the results from NASA-TLX indicate that not only is it helpful to engage the student haptically, but also spatially. For example, "It was very easy to get the subnets to the size that I wanted and then put them into the space where it was needed" (P08).

This allows the researcher to state that it was, according to the pedagogical principles of constructivism and through implementing those principles in ARCS inspired software, possible to build a compelling VLE system wherein problem-solving oriented learning with multi-modal and spatial elements allow the learning of primarily virtual concepts and skills more easily and with less learner stress. This concept is reinforced in other works such as Avilés-Cruz & Villegas-Cortez (2019), Goodwin et al. (2015). This research and past work indicate the implementation of VLEs needs to better leverage the powerful positive qualities only available in virtual environments.

Integrated Findings

The resonating narrative that emerged during data analysis indicates that cognitive load experienced during the VRIPS learning process was significantly less than traditional learning methods. The lessening of cognitive load allows for a less stressful learning process (Sweller, 1988). Experimental participants encountered a new virtual environment that required additional physical and mental additional effort and higher initial cognitive processing to start using VRIPS and begin assignments. Despite the additional hurdles required, participants indicated in NASA-TLX scores, that they were able to complete the assignments without feeling pressured or overwhelmed. As compared to the Control group that indicated significantly higher cognitive load in four of the NASA-TLX's six categories and raw scores. This supports the idea that students build mental schema presented in VR more rapidly than in traditional paper and pencil learning methods.

In the case of the overall NASA-TLX raw scores multiple statements regarding the ease of use occurred such as, “It [VRIPS] was easy to use. So, I think it was more fun than just having a piece of paper and just subnetting on a piece of paper.” (P02). When asked about the VRIPS process multiple participants made statements similar to the example above. These statements are congruent with NASA-TLX raw score results showing that the experimental group performed with significantly less cognitive load. Both results are consistent with work by Liu et al. (2022) and Dan and Reiner (2017) indicating that VR environments resulted in lower cognitive loads for the learner.

The spatial nature of problem description in VRIPS and the ability to visually and physically manipulate the elements within problem and solution that were previously entirely abstract elements to the learner intersect with statements from participants such as, “Just saying something and thinking about it in my mind is difficult, but actually doing it and having a physical aspect to it helps a lot, and I think it would help people that are more in the practical thinking than logical thinking aspect” (P04). This type of statement is supported by the NASA-TLX results and supported by research by Breves and Stein (2022) and Elford (2022) indicating that increased spatial presence in a VLE does not increase the cognitive load. Spatial learning in VR settings is explored by Srivastava et al. (2019) in their research, finding that for specific tasks the spatial aspect added to the learning experience.

A large amount of research has been done regarding dizziness and nausea in virtual environments (Gavgani et al., 2017; Guna et al., 2019; Rebenitsch & Owen, 2016; Saredakis et al., 2020). The most often cited reasons for virtual reality illness low quality video (image resolution and frame rate), subject matter (fast-paced action-oriented content vs. scenic experiences), and locomotion (user body movement within the VR experience). This research encountered a theme where participants struggled with issues defined here as “over immersion”. Once engaged in the VRIPS software they became disconnected with the physical world in such a way that they struggled to keep a kinesthetic relationship with their own body. This made it more difficult to complete tasks in VRIPs. Regarding the virtual to physical world overlap participants stated, “not being able to see the outside world was very weird for me because I had to bend down and I didn't know if I was going to hit the floor or not” (P04). The VRIPS experience only provides virtual hands which overlap the users’ physical hands. Due to issues like these users could have experienced higher cognitive load in the physical subcategories of the NASA-TLX.

Instructors Use of VR as a Teaching Modality

Instructors are being encouraged to provide students with multiple avenues to connect with learning and multiple modalities in which to do it (Picciano, 2009; Verde & Valero, 2021). A virtual reality learning experience/environment provides educators with additional opportunities to connect with students in new modalities. The provisioning of multiple modalities allows the instructor to meet the student in the student’s best learning environment. Thus, providing the greater opportunity of having the student quickly build the mental schema needed to retain and access the knowledge and skills learned.

This research posits that VLEs are not a replacement for existing teaching methods. However, they could be used as part of blended learning instruction allowing students to experience and understand material in additional or new modalities. The successful implementation of custom VLE and VR experiences would need the support of schools and institutions. They would need to assist with facilities, equipment, and most importantly curricular and professional development of the instructor.

The researcher suggests that instructors will need to be cognizant of several factors that became clear over the course of this research. Understanding that the physical nature of VR equipment, currently, has some user issues that need to be addressed. Several participants expressed issues with their inability to make the headset fit on their head and struggled to reach buttons on the controllers with their fingers. These issues are likely to be more pronounced as the age of the learner decreases and average body sizes also decrease. As discussed earlier the VR hardware market is advancing rapidly (Fink, 2019) with near-term advancements including hand-tracking, therefore no physical controllers, and advancements in headset design to reduce size and weight that could alleviate issues participants struggled with in the study. It is recommended that instructors using currently available equipment ensure to spend the necessary time to fit equipment to the learner comfortably to maximize the learning experience. This is consistent with other relevant studies (Bower et al., 2020; Klimova, 2021; Sarapak et al., 2022; Yildirim et al., 2020).

It is important that instructors wishing to use VR in an educational context understand the virtual immersion issues that may arise for some users. Current VR technology has made huge strides in eliminating motion sickness or dizziness (Saredakis et al., 2020). Over immersion in the VR experience is something that needs to be expected and explained ahead of time to users, until more standards for VR experiences are developed and become culturally normal (Higgens, 2018; Nicas, 2016). This researcher recommends reviewing a video of the VR environment or live casting a demonstration of the application to a physical screen with learners before VLE use to help prepare their perspective within the VR experience. Learning implement existing skills in a VR environment (photo editing, 2D video game play, video viewing) would also help to link existing mental models to new modalities (Gibson, 2014).

Experience and results from this study indicate that instructors desiring to use VR as a learning modality need to take into consideration more than just the learning outcomes of the process. VR should be used in conjunction with current modalities of learning, expanding, and blending with existing curriculum (Facebook et al., 2021; Spatial, 2021). Instructors may need extra time to overcome physical and physical/virtual aspects of the VR environment both in the selection of appropriate VR experience, also with the novel aspects of a VLE. Additional research to understand the finer nuances of these concepts still needs to be explored.

Study Limitations

The research suffered from several drawbacks that limit its ability to be applied to larger populations. The primary limitation of small (n=28) sample size leaves the study underpowered. Further the sample was broken into disproportionate sized groups of learners that were not all at the same level of learning based on previous IP experience. While this complexity did provide more nuance of the data collected and in results this fact also weakened the overall power. A progression of Mann Whitney U tests were completed at .05 significance, the results of which may have benefited from inflated Type I errors.

In several of the tables in the body and appendices significance values were shown for individual classes. This was done to provide a larger context of the data analysis process. These results are only informative for that context and results were not based on those values.

Sampling for the participants was convenient. The study sample was taken from volunteer students who registered for ITS 2300 – Data Networking and ITS 4750 – Internet Engineering in the Fall of 22-23. The two courses were the only courses scheduled at the university that semester that covered basic IP networking as part of a learning objectives. The best statistical results use random sampling; however, this was not possible within the practical constraints of the study. As a result of the small sample size and convenient sampling frame the results of this study should not be generalized to a broader audience.

The NASA-TLX is a self-reported measure in six categories that records a subjective understanding of the participants' experience. However, participants could have not understood the NASA-TLX training or, as suggested by Braarud (2021), participant responses could overlap categories and responses could be a reflection of introspection rather than task reflection.

Suggestions for Future Research

The study conducted provided me with suggestions for further opportunities and expansion. While there is a limited population of students at the university level studying IP subnetting the sample size could be expanded to provide more statistical power and provide a greater depth of interview responses. Replicating this study with samples offering a greater diversity of genders and from different locations, cultures and ethnic backgrounds would provide a wider depth of results. Focusing future research upon early IP subnetting learners and learners with the least amount of VR experience would provide a more detailed understanding of the impact VR has on student learning.

Expanding the research instrumentation to include additional IP subnetting learning modalities such as a desktop and mobile versions of the VRIPS application. This would allow learners without access to VR equipment to utilize the software. Also, it would provide additional data regarding the perspectives surrounding learners test scoring and cognitive issues. Mobile and desktop versions of VRIPS would also allow participants to access the software more often and for longer periods of time, allowing for a larger scope and depth of research.

Several instrumentation and data collection refinements would allow a more thorough exploration of VLEs impact upon student learning. Results from the NASA-TLX suggest that multiple physical modalities are involved in the use of VR environments. Refining, customizing, or expanding the NASA-TLX instrumentation would help investigating in these areas. Allowing the researcher access to data with more granularity. Adding instrumentation, data collection, analysis concerning student motivation and engagement adds deeper understanding of the learners lived experience.

There are many other abstract virtual instructional networking topics that should be investigated using VR applications. For example, IP network routing is another completely abstract and virtual concept that is difficult to teach in network design curriculums worldwide. Students struggle to visualize the path a packet will take from a source (like a smartphone) to a destination (like Facebook) and back. They also grapple with understanding the route decisions that are made for each packet along perhaps 20+ pieces of network equipment on that path that the packet travels through. VR offers the option to visualize this process. For instance, by virtually hooking the learners VR perspective to a single packet and "riding" it through the internet like a rollercoaster or train. VR also would allow the user to stop at each piece of network equipment on the path to examine or change the routing choices for that packet. Expanding upon that concept the VR user could be connected to live or simulated actual functioning networks permitting students to "ride" and work with live equipment in real time.

Not directly utilized in this study, the VRIPS application scored each problem the user worked on. This function could be expanded to include teams, leader boards and score sharing. Gamification in education has a long history of providing students with motivation and topical engagement (Pan et al., 2021). Moreover, leveraging these concepts would allow the instructor to track team and/or individual progress providing opportunities for individual student instruction for students that need extra help.

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Appendix A

IP Networking Subnetting Questions - Pre-Test Demographic Questions

1. Name (please print clearly):____
2. What is your age? ____________________
3. What gender do you identify as? _______________
4. Your ethnicity is:________________
5. Number of university hours completed
   (0-29 = 1st year, 30-59 = 2nd year, 60-89 = 3rd, 90+ = 4th year): ______________
6. Current cumulative/total GPA: _______________
7. Are you Pell Grant eligible: Y / N
8. Is your vision corrected to normal (glasses or contacts): Y / N
9. Previous IP Networking Experience:
   - 1 – Not at all
   - 2 – Slightly Familiar
   - 3 – Somewhat Familiar
   - 4 – Moderately Familiar
   - 5 – Extremely Familiar
10. Previous Virtual Reality Experience:
    - 1 – Not at all
    - 2 – Slightly Familiar
    - 3 – Somewhat Familiar
    - 4 – Moderately Familiar
    - 5 – Extremely Familiar
11. At what age did you receive your first smartphone? __________

12. Describe the number of computer devices/systems used at home (not including game consoles)?

13. Describe the number of game consoles used at home?

Appendix B

Pre-Test Questions

IP Subnetting Cheat Sheet

Mask Slash Notation	TOTAL # of IPs in Subnet	# usable IPs in Subnet (N-2)
/22	1024	1022
/23	512	510
/24	**256**	**254**
/25	128	126
/26	64	62
/27	32	30
/28	16	14
/29	8	6
/30	4	2
/31	2	0
/32	1	0

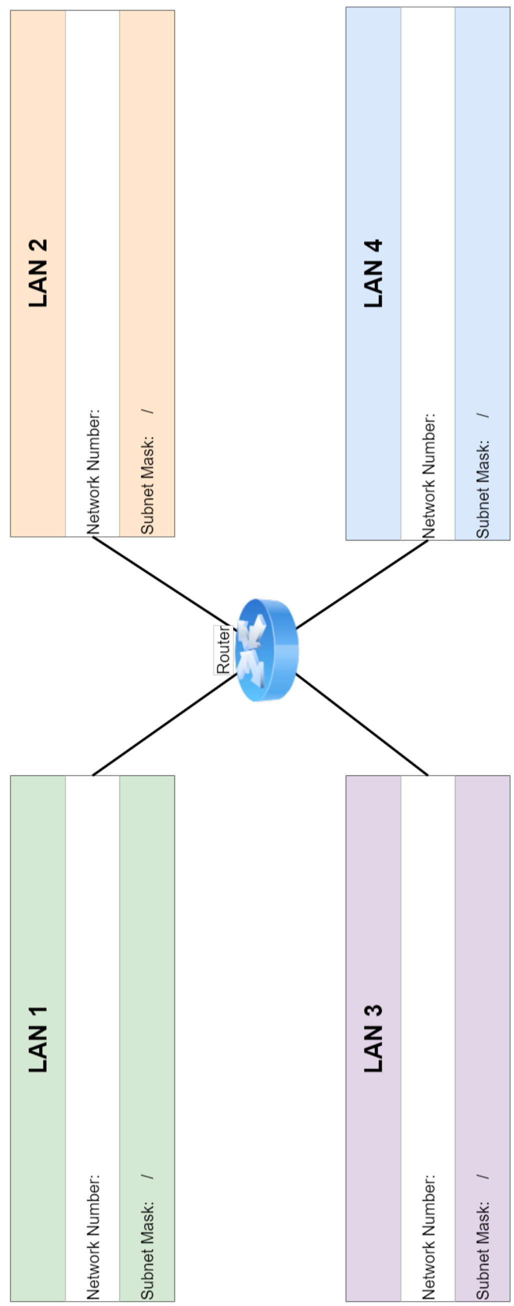
Note: Red text denotes the recommended starting point for subnetting.

Individual #1

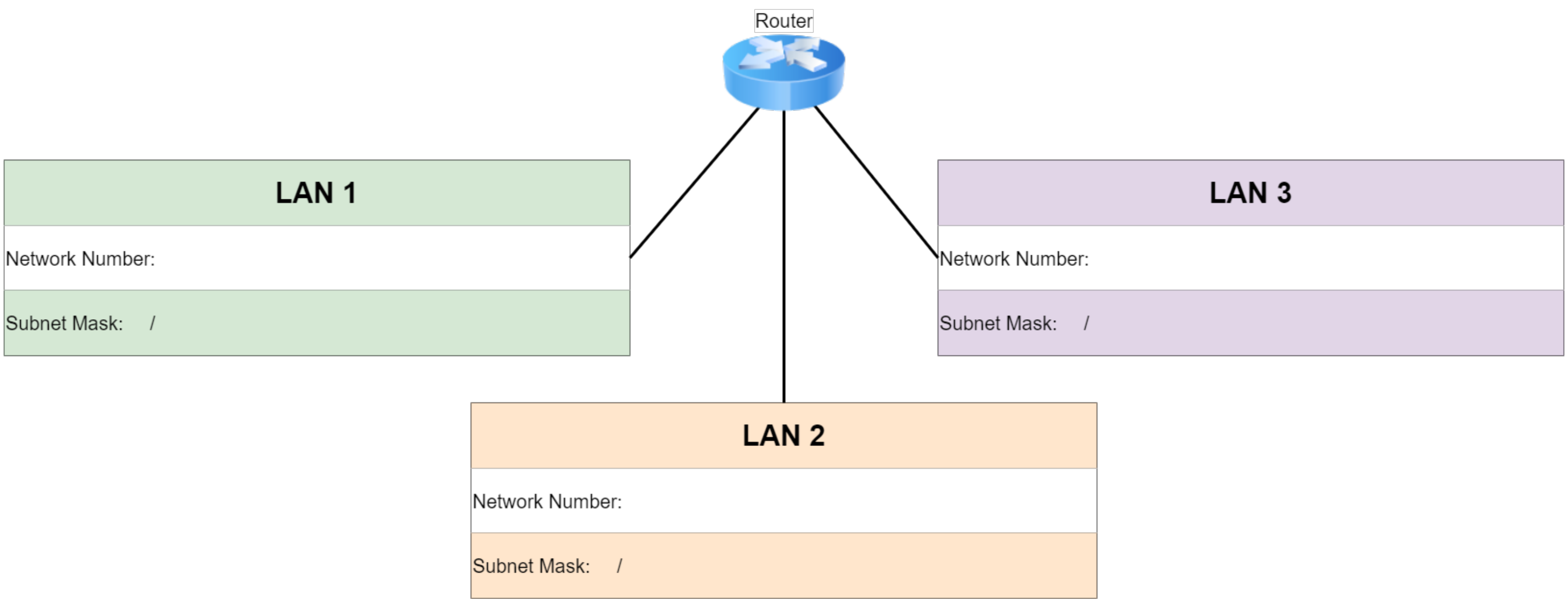
Name: ____

Date: ________________________________

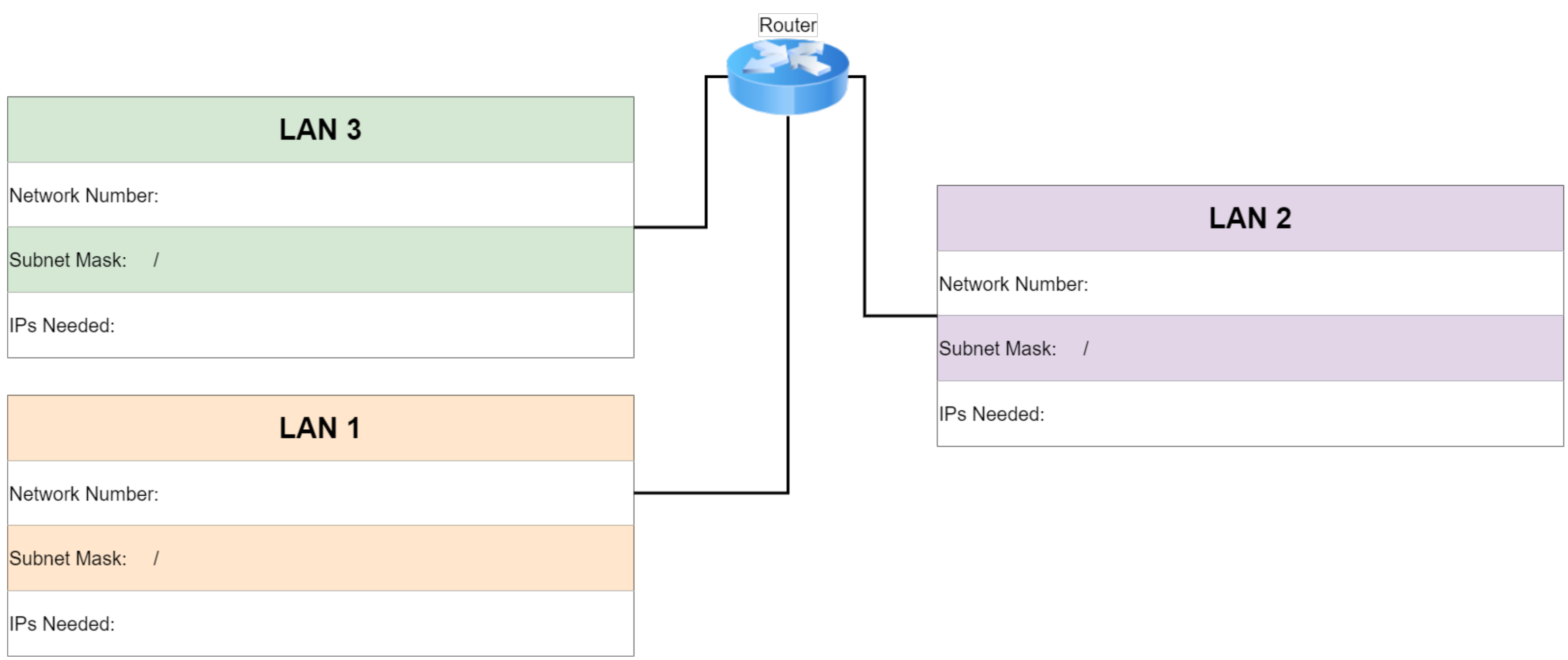
1. Subnet 12.56.85.0/24 into four equal parts. Answer should show network addresses and subnet masks.



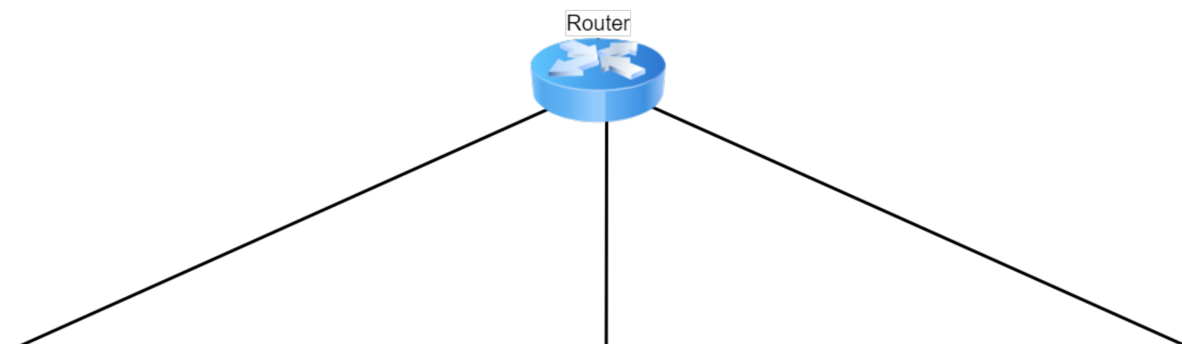
2. Using all available address space subnet 69.25.48.0/24 into three networks. All networks do not need to be the same size. Answer should show network addresses and subnet masks.



3. Subnet 144.25.88.0/24 into networks such that there are 120 IPs for LAN 1, 60 IPs for LAN 2 and 45 IPs for LAN 3. Answer should show network addresses and subnet masks and IPs needed.



4. Subnet 55.225.65.0/24 such that there are 20 IPs for LAN1, 115 IPs for LAN2 and 45 IPs for LAN3. Answer should provide for each network Network Number, Subnet Mask, Gateway IP, Broadcast IP, Number of usable IPs, and Total Number of IPs.



LAN 1	LAN 2	LAN 3
Network Number:	Network Number:	Network Number:
Subnet Mask: /	Subnet Mask: /	Subnet Mask: /
First Usable IP:	First Usable IP:	First Usable IP:
Gateway IP:	Gateway IP:	Gateway IP:
Broadcast IP:	Broadcast IP:	Broadcast IP:
Number of useable IPs (N-2):	Number of useable IPs (N-2):	Number of useable IPs (N-2):
Total Number of IP:	Total Number of IP:	Total Number of IP:

5. Using <u>all</u> available address space subnet 55.78.22.0/23 into three networks (LAN1, LAN2 and LAN3). Networks do **<u>not</u>** need to be same size.

   Answer should provide for **<u>each</u>** network:

   Network Name: **LAN1**

   Network Number:

   Subnet Mask: /

   Number of usable IPs in network:

   Network Name: **LAN2**

   Network Number:

   Subnet Mask: /

   Number of usable IPs in network:

   Network Name: **LAN3**

   Network Number:

   Subnet Mask: /

   Number of usable IPs in network:

6. Using <u>all</u> available address space subnet 125.58.64.0/22 into six networks.

   Named: Ohio, Iowa, Oregon, Arizona, Colorado, Montana

   Answer should provide for <u>**each**</u> network:

   Network Name:
   Network Number:
   Subnet Mask: /
   Number of usable IPs in network:

7. Subnet 95.14.36.0/24 such that there are (Not all IPs need be used):

32 IPs for the Americas Division network
60 IPs for the European Division network
28 IPs for the African Division network
26 for the Asian Division network
17 IPs for the Antarctica Division network

Network Name	**Americas Division**	Network Name	**Asian Division**
Subnet Mask	/	Subnet Mask	/
Network Number		Network Number	
Number of Usable IPs in network:		Number of Usable IPs in network:	
Network Name	**European Division**	Network Name	**Antarctica Division**
Subnet Mask	/	Subnet Mask	/
Network Number		Network Number	
Number of Usable IPs in network:		Number of Usable IPs in network:	
Network Name	**African Division**		
Subnet Mask	/		
Network Number			
Number of Usable IPs in network:			

8. Subnet 156.36.20.0/23 such that (not all IPs must be used):

   22 IPs for Interconnect Net
   48 IPs for Northeast Region Net
   151 IPs for Southeast Region Net
   12 IPs for the Northwest Region Net
   54 IPs for Southwest Region Net
   22 IPs for Employee Net
   10 IPs for Guest Net
   16 IPs for Lobby Net

   Answer should provide for **<u>each</u>** network:

   Network Name:
   Network Number:
   Subnet Mask: /
   Number of usable IPs in network:

9. Subnet 36.244.60.0/22 such that (not all IPs must be used):

   58 IPs for Sales Network
   111 IPs for Marketing Network
   15 IPs for the Manufacturing Network
   28 IPs for Accounting Network
   124 IPs for Interconnects Network
   222 IPs for IT Network
   10 IPs for Wi-Fi-Guest Network
   126 IPs for Printers Network

   Answer should provide for **<u>each</u>** network:

   Network Name:
   Network Number:
   Subnet Mask: /
   Number of usable IPs in network:

10. Subnet 104.225.48.0/20 such that (not all IPs must be used):

    258 IPs for Finance Network
    111 IPs for Marketing Network
    15 IPs for the Human Resources Network
    28 IPs for Quality Management Network
    124 IPs for Research and Development Network
    222 IPs for Legal Network
    1024 IPs for Wi-Fi-Guest Network
    126 IPs for Leadership Network

    Answer should provide for **<u>each</u>** network:

    Network Name:
    Network Number:
    Subnet Mask: /
    Number of usable IPs in network:

Appendix C

Post-Test Questions

IP Subnetting Cheat Sheet

Mask Slash Notation	TOTAL # of IPs in Subnet	# usable IPs in Subnet (N-2)
/22	1024	1022
/23	512	510
/24	**256**	**254**
/25	128	126
/26	64	62
/27	32	30
/28	16	14
/29	8	6
/30	4	2
/31	2	0
/32	1	0

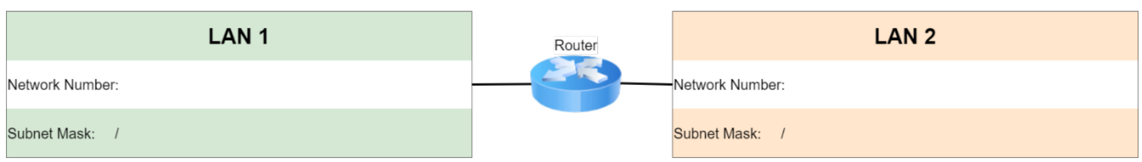
Note: Red text denotes the recommended starting point for subnetting.

Individual #2

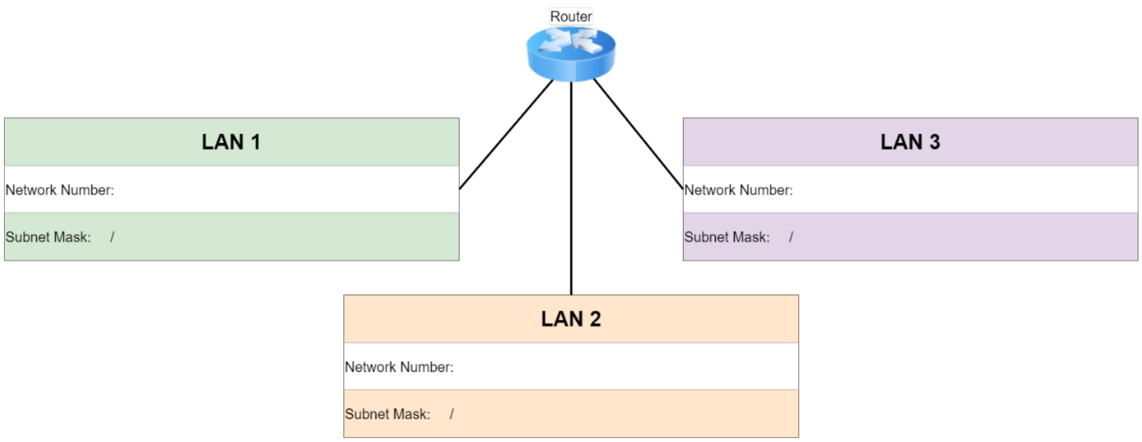
Name: ____

Date: ________________________

1. Subnet 192.168.1.0/24 into two equal parts. Answer should show network addresses and subnet masks.



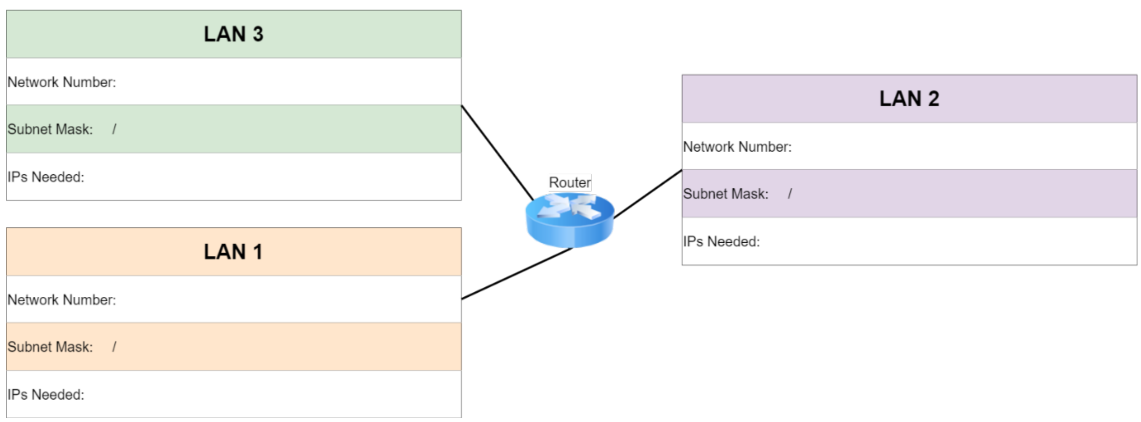
2. Using all available address space subnet 169.15.32.0/24 into three networks. All networks do not need to be the same size. Answer should show network addresses and subnet masks.



3. Subnet 44.65.188.0/24 into networks such that there are:

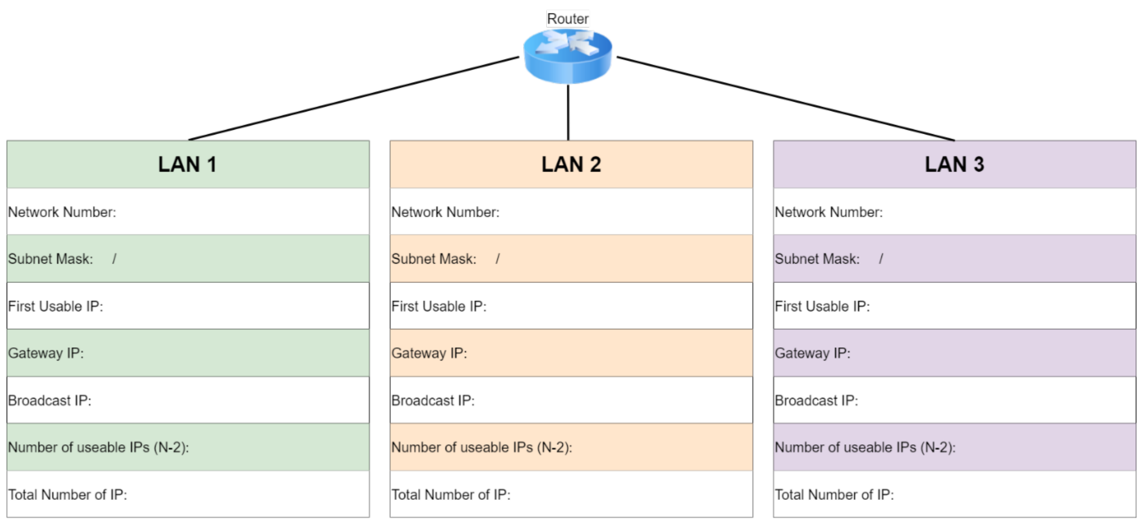
   LAN 1: 120 IPs
   LAN 2: 60 IPs
   LAN 3: 45 IPs

   Answer should show network addresses and subnet masks and IPs needed.



4. Subnet 55.225.65.0/24 such that there are:
   LAN 1: 20 IPs
   LAN 2: 115 IPs
   LAN 3: 45 IPs

   Answer should provide for each network: Network Number, Subnet Mask, First Useable IP, Gateway IP, Broadcast IP, Number of usable IPs, and Total Number of IPs



11. Using <u>all</u> available address space subnet 5.8.66.0/23 into three networks (LAN1, LAN2 and LAN3). Networks do **<u>not</u>** need to be same size.

    Answer should provide for **<u>each</u>** network:

    Network Name: **LAN1**

    Network Number:

    Subnet Mask: /

    Number of usable IPs in network:

    Network Name: **LAN2**

    Network Number:

    Subnet Mask: /

    Number of usable IPs in network:

    Network Name: **LAN3**

    Network Number:

    Subnet Mask: /

    Number of usable IPs in network:

12. Using <u>all</u> available address space subnet 12.158.164.0/22 into six networks.

    Named: California, Texas, Florida, Virginia, Alaska, Washington

    Answer should provide for **<u>each</u>** network:

    Network Name:
    Network Number:
    Subnet Mask: /
    Number of usable IPs in network:

13. Subnet 195.44.236.0/24 such that there are (Not all IPs need be used):

Red Network: 60 IPs
Blue Network: 32 IPs
Yellow Network: 26 IPs
Green Network: 22
Purple Network: 14 IPs

Network Name	**Red Network**	Network Name	**Blue Network**
Subnet Mask	/	Subnet Mask	/
Network Number		Network Number	
Number of Usable IPs in network:		Number of Usable IPs in network:	
Network Name	**Yellow Network**	Network Name	**Green Network**
Subnet Mask	/	Subnet Mask	/
Network Number		Network Number	
Number of Usable IPs in network:		Number of Usable IPs in network:	
Network Name	**Purple Network**		
Subnet Mask	/		
Network Number			
Number of Usable IPs in network:			

14. Subnet 244.35.10.0/23 such that (not all IPs must be used):

    Interconnects Network: 20 IPs
    Great Lakes Region Network: 46 IPs
    Mountain Region Network: 141 IPs
    Plains Region Network: 11 IPs
    Marshland Region Network: 53 IPs
    Ocean Region Network: 20 IPs
    Guest Network: 11 IPs
    Lobby Network: 16 IPs

    Answer should provide for **<u>each</u>** network:

    Network Name:
    Network Number:
    Subnet Mask: /
    Number of usable IPs in network:

15. Subnet 110.44.60.0/22 such that (not all IPs must be used):

    Car Network: 56 IPs
    Truck Network: 112 IPs
    Van Network: 16 IPs
    Plane Network: 26 IPs
    Train Network: 128 IPs
    Boat Network: 220 IPs
    Wi-Fi-Guest Network: 11 IPs
    Printers Network: 126 IPs

    Answer should provide for **each** network:

    Network Name:
    Network Number:
    Subnet Mask: /
    Number of usable IPs in network:

16. Subnet 104.225.48.0/20 such that (not all IPs must be used):

    Earth Network: 258 IPs
    Moon Network: 111 IPs
    Venus Network:15 IPs
    Mars Network: 28 IPs
    Jupiter Network: 124 IPs
    Saturn Network: 222 IPs
    Wi-Fi-Guest Network: 1024 IPs
    Astronauts Network: 126 IPs

    Answer should provide for **each** network:

    Network Name:
    Network Number:
    Subnet Mask: /
    Number of usable IPs in network:

Appendix D

Interview Questions

Interview Question		Rationale for the Question (Theme of the inquiry)
1.	How many VR experiences have you had?	To warm up the interviewee by talking with them about their general VR experiences.
2.	How many other VR **learning experiences** have you had?	Explore participants' experience with VR as a learning tool.
3.	Why did you sign up for this course?	To understand the participants initial motivation for learning the material.
4.	How do you see utilizing the IP networking material learned in the future?	Exploring relevance of experience from user's perspective. (Relevance)
5.	When you started VRIPS what was the first object you saw in VR?	To focus on the beginning of the VRIPS experience.
6.	Describe the process you used to solve the subnetting exercises?	Gather understanding of the mental process the student used to complete the exercises.
7.	Thinking about the process you used how did the VR experience affect it?	How the student believes VR impacted the activity.
The following questions center around the NASA-TLX survey data. Participants will be provided with their own data as well as average data for the EG group. Question priority is given to the questions related to NASA-TLX area showing extreme scores (1-5 or 15-20).		
8.	Thinking about the mental activity needed to complete the exercises in the VR experience. What elements hindered your learning?	Exploring issues related to the mental demands of VR Experience. (NASA-TLX - Mental Demand)
9.	Recalling the physical activity needed to complete the VR experience how did it impact, positive or negatively, the completion of the exercises?	To understand the participants' physical relationship to interactions within the experience. (NASA-TLX - Physical Demand)
10.	Looking back on the VR experience how did the time limits affect the completion of exercises?	Gather details about temporal effects related to task completion. (NASA-TLX - Temporal Demand)
11.	Recalling your performance during the VR experience, describe your satisfaction level to accomplish the tasks set by the exercises?	Gain understanding about satisfaction of performance (NASA-TLX - Performance)
12.	Thinking about the mental and physical work required to accomplish the exercises what significant issues limited your experience?	Explore reasons why participant provided the indicated level of mental and physical (NASA-TLX - Effort)
13.	Thinking back to issues that kept you from accomplishing tasks in the experience what were major issues that contributed to that?	Learning about issues that provided disappointment and annoyance during VR experience (NASA-TLX - Frustration)
An opportunity for general discussion about the VR experience		

Appendix E

NASA-TLX Survey

VRIPS NASA TLX Survey

Name: ______________________________

Mental Demand	Low – High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low – High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low – High	How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good – Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low – High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low – High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

V1.1

Appendix F

Informed Consent to Participate in a Research Project

Ohio University Adult Consent Form with Signature

Title of Research: Impact of Virtual Learning Environments upon Computer Network Education

Researchers: Douglas R. Bowie and Greg Kessler
IRB number: 22-X-84

You are being asked by an Ohio University researcher to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks of the research project. It also explains how your personal information/biospecimens will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

Summary of Study

The purpose of this study is to explore the understandings and perceptions of university students' utilization of a virtual learning environment to learn computer networking concepts.

Explanation of Study

This study is being done to expand about the effect of virtual learning environments upon students' comprehension of computer networking. The goal is to understand more about how to best present introductory computer networking material to students.

If you agree to participate, you will be asked to participate in a pre-test and post-test to measure learning, a survey of your perspective with regards to the difficulty of the virtual environment, and a may be asked to participate in a brief interview about your experiences.

Your participation in the study will last one to two weeks with the possibility of being asked to participate in a follow-up interview session.

Risks and Discomforts

No risks or discomforts are anticipated.

Benefits

This research will help educators understand of how students learn computer networking concepts.

Confidentiality and Records

Your study information will be kept confidential by securing any personally identifiable information in encrypted storage. Data will only be viewed be qualified research faculty and staff.

Your study data will be destroyed on May 1st, 2025. No identifiers of the participants (such as personal names) will be presented in the final paper.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

<u>Compensation</u>

If selected for an interview as compensation for your time/effort, you will receive a $10 gift card.

Please be aware that certain personal information, such as name, address, and social security number, may be provided to the Ohio University Finance Office to document that you received payment for research participation. However, your study data will not be shared with Finance.

<u>Future Use Statement</u>

Identifiers might be removed from data/samples collected, and after such removal, the data/samples may be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you or your legally authorized representative.

Contact Information

If you have any questions regarding this study, please contact the investigator Douglas R. Bowie, db289903@ohio.edu, 740.331.4281or the advisor Greg Kessler, kessler@ohio.edu, 740.593.2748.

If you have any questions regarding your rights as a research participant, please contact the Director of Research Compliance, Ohio University, (740)593-0664 or compliance@ohio.edu.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered;
- you have been informed of potential risks and they have been explained to your satisfaction;
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study;
- you are 18 years of age or older;
- your participation in this research is completely voluntary;
- you may leave the study at any time; if you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled.

Signature____Date______________

Printed Name____

Version Date: 06/13/22

Appendix G

Treatment Schedule

VRIPS Treatment Schedule
Lecture - M, W - 80 mins
Lab Period - Thu - 80 mins

Monday	Tuesday	Wednesday	Thursday - Experiment	Thurs - Control	Future
Bowie Method IP Subnetting Lecture and Slides with Topical Handouts		Small Group Work using simple practical examples. Faculty moves between groups providing instructional support as needed.	Oculus Quest VR Training and then VRIPS experience		Individual Semi-Structured Interviews

All Students		All Students	2 Lab sections (half in control half in experimental)		

80 mins - Lecture and Slides		**80 mins**	**80 mins**	**80 mins**	**30-60 Mins**
		30 min - Small groups working multiple example problems of increasing difficulty	10 mins - Student VR Exploratory Time	10 mins - wait for them all to show	
			30 mins - VRIPS	30 Mins - Control Group	
		10 Min - Faculty demo of VRIPS instrument	10 mins - NASA-TLX	10 mins - NASA-TLX	
		10 Min - Consent form and descriptive statstics collection	30 min - Post-Test	30 Mins - Post-Test	
		30 min - Pre-Test			
Q&A as needed		Q&A as needed	Q&A as needed		

Appendix H

Control Group Activity

IP Subnetting Cheat Sheet

Mask Slash Notation	TOTAL # of IPs in Subnet	# usable IPs in Subnet (N-2)
/22	1024	1022
/23	512	510
/24	**256**	**254**
/25	128	126
/26	64	62
/27	32	30
/28	16	14
/29	8	6
/30	4	2
/31	2	0
/32	1	0

Note: Red text denotes the recommended starting point for subnetting.

Individual #3

Name: ____

Date: ____________________________

1. Divide 11.125.66.0/24 into two parts. Assign a network to each LAN.

LAN1
Network Number:

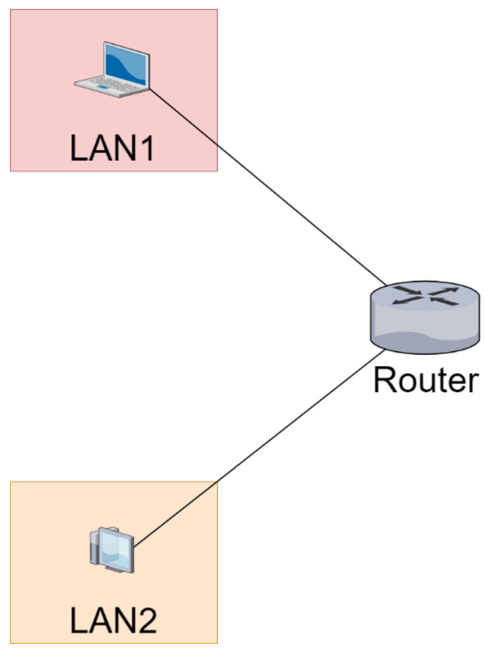
Subnet Mask: /

Usable IPs in network:

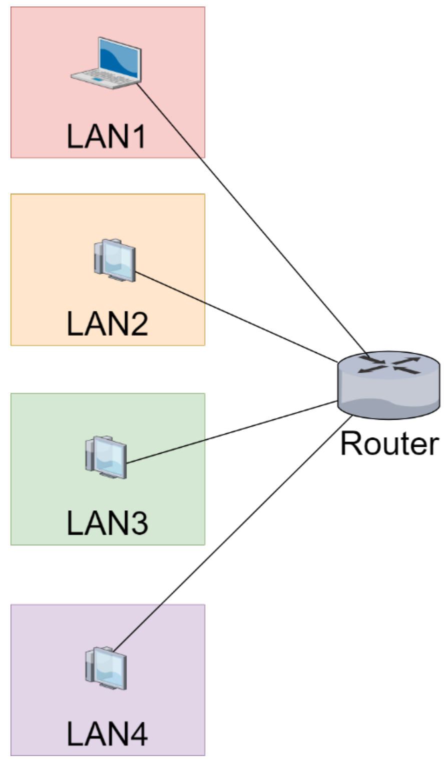
LAN2
Network Number:

Subnet Mask: /

Usable IPs in network:



2. Divide 113.65.71.0/24 into four equal parts. Assign a network to each LAN.



LAN1
Network Number:

Subnet Mask: /

Usable IPs in network:

LAN2
Network Number:

Subnet Mask: /

Usable IPs in network:

LAN3
Network Number:

Subnet Mask: /

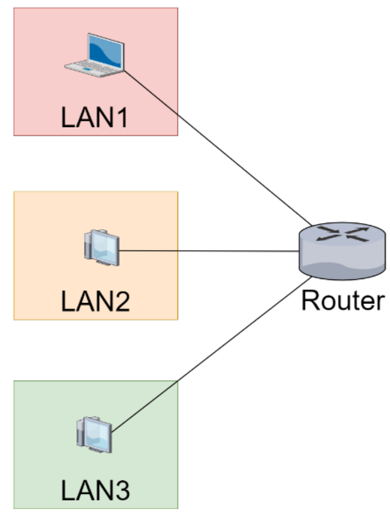
Usable IPs in network:

LAN4
Network Number:

Subnet Mask: /

Usable IPs in network:

3. Using all available address space divide 254.60.87.128/25 into three networks. Use the largest network for LAN1. All networks do NOT need to be the same size.



LAN1
Network Number:

Subnet Mask: /

Usable IPs in network:

LAN2
Network Number:

Subnet Mask: /

Usable IPs in network:

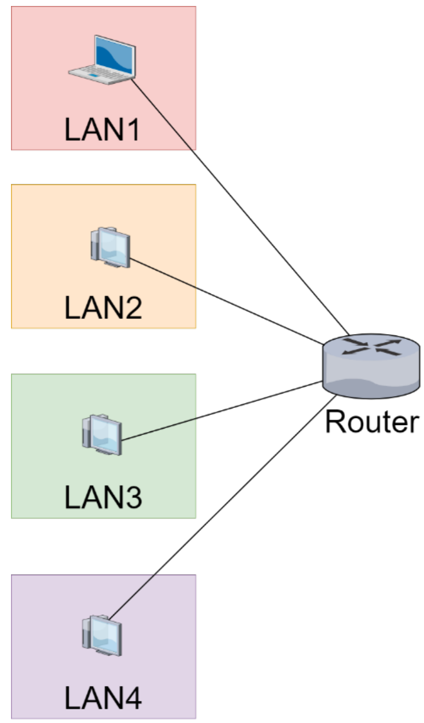
LAN3
Network Number:

Subnet Mask: /

Usable IPs in network:

4. Subnet 145.66.88.0/24 such that (not all IPs must be used):

   110 IPs for LAN1
   52 IPs for LAN2
   12 IPs for LAN3
   8 IPs for LAN4



   LAN1
   Network Number:

   Subnet Mask: /

   Usable IPs in network:

   LAN2
   Network Number:

   Subnet Mask: /

   Usable IPs in network:

   LAN3
   Network Number:

   Subnet Mask: /

   Usable IPs in network:

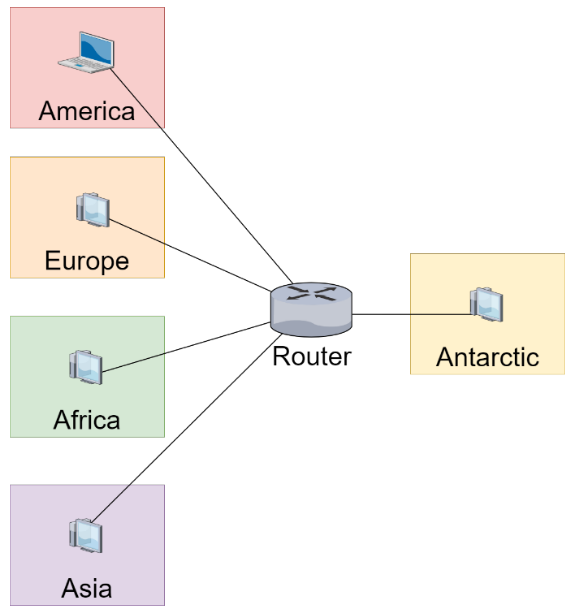
   LAN4
   Network Number:

   Subnet Mask: /

   Usable IPs in network:

5. Subnet 195.132.48.0/22 such that (not all IPs must be used):

32 IPs for the Americas Division
60 IPs for the European Division
28 IPs for the African Division
26 for the Asian Division
17 IPs for the Antarctica Division



Americas Division
Network Number:

Subnet Mask: /

Usable IPs in network:

European Division
Network Number:

Subnet Mask: /

Usable IPs in network:

African Division
Network Number:

Subnet Mask: /

Usable IPs in network:

Asian Division
Network Number:

Subnet Mask: /

Usable IPs in network:

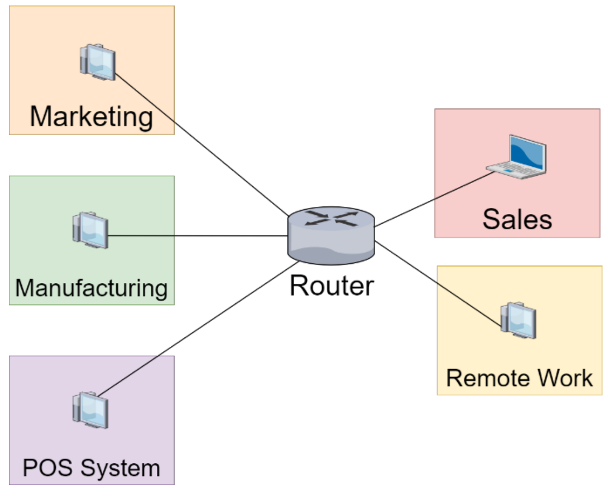
Antarctica Division
Network Number:

Subnet Mask: /

Usable IPs in network:

6. Subnet 95.211.32.0/20 such that (not all IPs must be used):

12 IPs for Sales
100 IPs for Marketing
228 IPs for Manufacturing
981 for the POS System
1017 IPs for Remote Work



Sales
Network Number:

Subnet Mask: /

Usable IPs in network:

Marketing
Network Number:

Subnet Mask: /

Usable IPs in network:

Manufacturing
Network Number:

Subnet Mask: /

Usable IPs in network:

POS
Network Number:

Subnet Mask: /

Usable IPs in network:

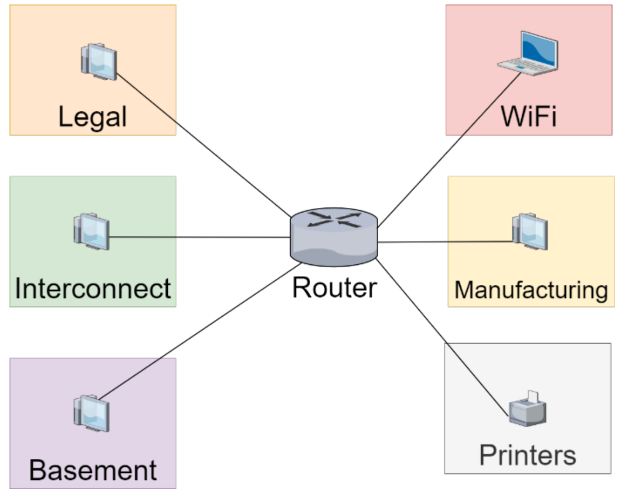
Remote Work
Network Number:

Subnet Mask: /

Usable IPs in network:

7. Subnet 199.58.240.0/21 such that (not all IPs must be used):

2 IPs for Interconnect
6 IPs for Legal
14 IPs for Basement
20 for the Manufacturing
8 IPs for Printers
18 IPs for Wi-Fi



Interconnect
Network Number:

Subnet Mask: /

Usable IPs in network:

Legal
Network Number:

Subnet Mask: /

Usable IPs in network:

Basement
Network Number:

Subnet Mask: /

Usable IPs in network:

Manufacturing
Network Number:

Subnet Mask: /

Usable IPs in network:

Printers
Network Number:

Subnet Mask: /

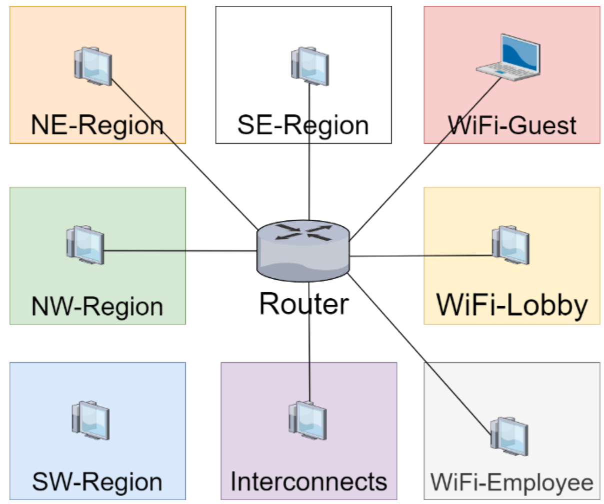
Usable IPs in network:

Wi-Fi
Network Number:

Subnet Mask: /

Usable IPs in network:

8. Subnet 58.236.40.0/22 such that (not all IPs must be used):
   24 IPs for Interconnects
   58 IPs for North East Region
   251 IPs for South East Region
   5 for the North West Region
   128 IPs for South West Region
   22 IPs for Wi-Fi-Employee
   100 IPs for Wi-Fi-Guest
   6 IPs for Wi-Fi-Lobby



Interconnect
Network Number:

Subnet Mask: /

Usable IPs in network:

North East Region
Network Number:

Subnet Mask: /

Usable IPs in network:

South East Region
Network Number:

Subnet Mask: /

Usable IPs in network:

North West Region
Network Number:

Subnet Mask: /

Usable IPs in network:

South West Region
Network Number:

Subnet Mask: /

Usable IPs in network:

Wi-Fi Employee
Network Number:

Subnet Mask: /

Usable IPs in network:

Wi-Fi Guest
Network Number:

Subnet Mask: /

Usable IPs in network:

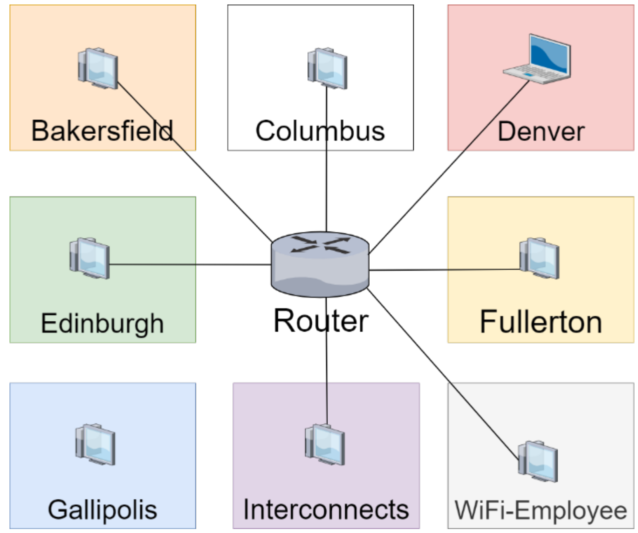
Wi-Fi Lobby
Network Number:

Subnet Mask: /

Usable IPs in network:

9. Subnet 60.134.16.0/21 such that (not all IPs must be used):

124 IPs for Interconnects
92 IPs for Bakersfield
168 IPs for Columbus
15 for the Denver
132 IPs for Edinburgh
16 IPs for Fullerton
110 IPs for Gallipolis
4 IPs for Honolulu



Interconnect
Network Number:

Subnet Mask: /

Usable IPs in network:

Edinburgh
Network Number:

Subnet Mask: /

Usable IPs in network:

Bakersfield
Network Number:

Subnet Mask: /

Usable IPs in network:

Fullerton
Network Number:

Subnet Mask: /

Usable IPs in network:

Columbus
Network Number:

Subnet Mask: /

Usable IPs in network:

Gallipolis
Network Number:

Subnet Mask: /

Usable IPs in network:

Denver
Network Number:

Subnet Mask: /

Usable IPs in network:

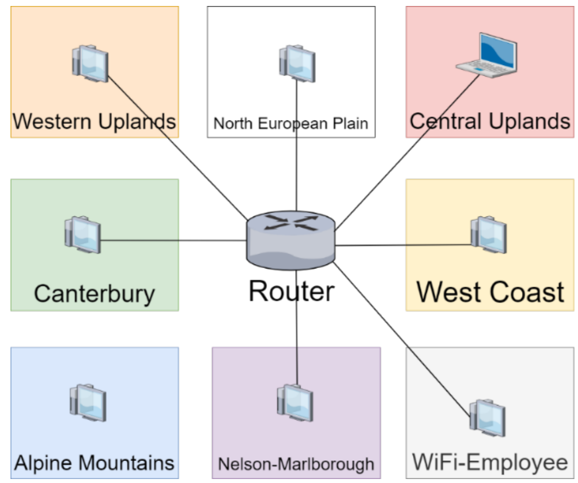
Honolulu
Network Number:

Subnet Mask: /

Usable IPs in network:

10. Subnet 80.34.112.0/20 such that (not all IPs must be used):

408 IPs for Western Uplands
185 IPs for North European Plain
205 IPs for Central Uplands
68 for the Alpine Mountains
85 IPs for Nelson-Marlborough
512 IPs for West Coast
321 IPs for Canterbury
333 IPs for Otago



Western Uplands
Network Number:

Subnet Mask: /

Usable IPs in network:

Nelson Marlborough
Network Number:

Subnet Mask: /

Usable IPs in network:

North European Plains
Network Number:

Subnet Mask: /

Usable IPs in network:

West Coast
Network Number:

Subnet Mask: /

Usable IPs in network:

Central Uplands
Network Number:

Subnet Mask: /

Usable IPs in network:

Canterbury
Network Number:

Subnet Mask: /

Usable IPs in network:

Alpine Mountains
Network Number:

Subnet Mask: /

Usable IPs in network:

Otago
Network Number:

Subnet Mask: /

Usable IPs in network:

Appendix I

IRB Approval

LEO: IRB PROTOCOL 22-X-84 APPROVED
1 message

compliance@ohio.edu <compliance@ohio.edu> Thu, Aug 18, 2022 at 10:00 AM
To: bowie@ohio.edu

LEO V3

Project Number	22-X-84
Project Status	APPROVED
Committee:	Social/Behavioral IRB
Compliance Contact:	Lori Miller (lorimiller@ohio.edu)
Primary Investigator:	Douglas Bowie
Project Title:	Impact of Virtual Learning Environments upon Computer Network Education
Level of Review:	EXPEDITED

The Social/Behavioral IRB reviewed and approved by expedited review the above referenced research. The Board was able to provide expedited approval under 45 CFR 46.110(b)(1) because the research meets the applicability criteria and one or more categories of research eligible for expedited review, as indicated below.

IRB Approved:	08/18/2022 10:00:46 AM
Expiration:	08/18/2023
Review Category:	6,7

Waivers: No waivers are granted with this approval.

If applicable, informed consent (and HIPAA research authorization) must be obtained from subjects or their legally authorized representatives and documented prior to research involvement. In addition, FERPA, PPRA, and other authorizations / agreements must be obtained, if needed. The IRB-approved consent form and process must be used. Any changes in the research (e.g., recruitment procedures, advertisements, enrollment numbers, etc.) or informed consent process must be approved by the IRB before they are implemented (except where necessary to eliminate apparent immediate hazards to subjects).

The approval will no longer be in effect on the date listed above as the IRB expiration date. A Periodic Review application must be approved within this interval to avoid expiration of the IRB approval and cessation of all research activities. All records relating to the research (including signed consent forms) must be retained and available for audit for at least three (3) years after the research has ended.

It is the responsibility of all investigators and research staff to promptly report to the Office of Research Compliance / IRB any serious, unexpected and related adverse and potential unanticipated problems involving risks to subjects or others.

This approval is issued under the Ohio University OHRP Federalwide Assurance #00000095. Please feel free to contact the Office of Research Compliance staff contact listed above with any questions or concerns.

The approval will no longer be in effect when the Primary Investigator is no longer under the auspices of Ohio University, e.g., graduation or departure from Ohio University.

Research Compliance
117 Research and Technology Center 740.593.0664
compliance@ohio.edu

Appendix J

Change Score Paired T Test Results

		Levene's				t-test for Equality of Means								
						Significance			Std. Error	95% CI		Effect		
Cases	N	F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Difference	Lower	Upper	Cohen's d	Hedges's g	Size
All	28	1.369	.253	.127	26	.450	.900	.052	.411	-.793	.897	1.077	1.109	Large Effect
ITS 2300	20	1.719	.206	-.610	18	.275	.549	-.292	.478	-1.296	.712	1.047	1.093	Large Effect
ITS 4750	8	.077	.791	.933	6	.193	.387	.750	.804	-1.216	2.716	1.137	1.258	Large Effect

Effect Size *r* less than 0.2 -> small effect

Effect Size *r* between 0.2 and 0.5 -> medium effect

Effect Size *r* greater than 0.8 -> large effect

Appendix K

NASA-TLX Results

		Mann-Whitney U Test			Effect			
	N	Z	U	Exact Sig.	r	r^2	r%	Size
All Cases								
Mental	28	-2.164	49.5	0.029	0.409	0.17	16.72%	Medium Effect
Physical	28	-1.007	74.5	0.324	0.190	0.04	3.62%	
Temporal	28	-2.214	48.8	0.025	0.418	0.18	17.51%	Medium Effect
Performance	28	-1.169	71.0	0.26	0.221	0.05	4.88%	
Effort	28	-2.702	38.0	0.006	0.511	0.26	26.07%	Large Effect
Frustration	28	-3.333	24.5	< .001	0.630	0.4	39.67%	Large Effect
Total	28	-2.021	52.5	0.042	0.382	0.15	14.59%	Medium Effect
ITS 2300								
Mental	20	-1.858	24.0	.069	0.415	0.17	17.26%	
Physical	20	-.078	47.0	.970	0.017	0	0.03%	
Temporal	20	-2.252	19.0	.025	0.504	0.25	25.36%	Large Effect
Performance	20	-.663	39.5	.521	0.148	0.02	2.20%	
Effort	20	-2.863	11.0	.003	0.640	0.41	40.98%	Large Effect
Frustration	20	-2.410	17.0	.016	0.539	0.29	29.04%	Large Effect
Total	20	-2.393	17.0	.016	0.535	0.29	28.63%	Large Effect
ITS 4750								
Mental	8	-1.479	3.0	.200	.523	0.27	27.34%	
Physical	8	-1.452	3.0	.200	.513	0.26	26.35%	
Temporal	8	-.730	5.5	.486	.258	0.07	6.66%	
Performance	8	-1.023	4.5	.343	.362	0.13	13.08%	
Effort	8	-.871	5.0	.486	.308	0.09	9.48%	
Frustration	8	-2.337	0.0	.290	.826	0.68	68.27%	
Total	8	.000	8.0	1.000	.000	0	0.00%	

Effect size only listed for categories that show statistical significance (Exact Sig.<0.05).
Effect Size *r* less than 0.3 -> small effect
Effect Size *r* between 0.3 and 0.5 -> medium effect
Effect Size *r* greater than 0.5 -> large effect

Appendix L

Paired T Test Results - Test Scores

	N	M	SD	t	df	95% CI Lower	95% CI Upper	Significance One-Sided p	Significance Two-Sided p	Cohen's d	Effect Hedges's g	Size
All Cases												
Pre-Test	28	5.339	1.599	-9.028	27	-2.214	-1.394	<.001	<.001	1.057	1.088	Large
Post-Test	28	7.143	1.835									
Control												
Pre-Test	12	5.542	1.406	-6.449	11	-2.459	-1.208	<.001	<.001	.985	1.059	Large
Post-Test	12	7.375	1.848									
Experimental												
Pre-Test	16	5.188	1.760	-6.252	15	-2.389	-1.174	<.001	<.001	1.140	1.201	Large
Post-Test	16	6.969	1.866									
ITS 2300												
Pre-Test	20	4.8	1.525	-7.276	19	-2.157	-1.193	<.001	<.001	1.030	1.073	Large
Post-Test	20	6.475	1.682									
ITS 4750												
Pre-Test	8	6.688	.799	-5.338	7	-3.066	-1.184	<.001	<.001	1.126	1.268	Large
Post-Test	8	8.813	.923									
ITS 2300 Control												
Pre-Test	8	4.938	1.321	-5.020	7	-2.207	-.793	<.001	.002	.845	.952	Large
Post-Test	8	6.438	1.499									
ITS 2300 Experimental												
Pre-Test	12	4.708	1.698	-5.364	11	-2.527	-1.056	<.001	<.001	1.157	1.244	Large
Post-Test	12	6.5	1.859									
ITS 4750 Control												
Pre-Test	4	6.75	.500	-5.000	3	-4.091	-.909	.008	.015	1.000	1.382	Large
Post-Test	4	9.25	.500									
ITS 4750 Experimental												
Pre-Test	4	6.625	1.109	-2.782	3	-3.752	.252	.034	.069	1.258	1.739	Large
Post-Test	4	8.375	1.109									

Effect Size Hedge's g less than 0.2 -> small effect

Effect Size Hedge's g between 0.2 and 0.5 -> medium effect

Effect Size Hedge's g greater than 0.8 -> large effect

Appendix M

Testing Score Descriptive Statistics

	N	Mean	Std. Deviation	Variance	Skewness	Skewness Std. Error	Kurtosis	Kurtosis Std. Error
Combined								
pre-test	28							
Control	12	5.542	1.406	1.975	-0.514	0.637	-1.554	1.232
Experiment	16	5.188	1.760	3.096	0.724	0.564	-0.404	1.091
post-test	28							
Control	12	7.375	1.848	3.415	-0.463	0.637	-0.729	1.232
Experiment	16	6.969	1.866	3.482	-0.375	0.564	-0.020	1.091
pre to post Difference	28							
Control	12	1.833	0.985	0.970	0.216	0.637	2.121	1.232
Experiment	16	1.781	1.139	1.299	0.043	0.564	-0.555	1.091
ITS 2300								
pre-test	20							
Control	8	4.938	1.321	1.746	0.117	0.752	-2.269	1.481
Experiment	12	4.708	1.698	2.884	1.658	0.637	2.898	1.232
post-test	20							
Control	8	6.438	1.499	2.246	-0.392	0.752	-0.746	1.481
Experiment	12	6.500	1.859	3.455	-0.051	0.637	0.370	1.232
pre to post Difference	20							
Control	8	1.500	0.845	0.714	-0.947	0.752	-0.028	1.481
Experiment	12	1.792	1.157	1.339	0.295	0.637	-0.435	1.232
ITS 4750								
pre-test	8							
Control	4	6.750	0.500	0.250	-2.000	1.014	4.000	2.619
Experiment	4	6.625	1.109	1.229	-1.720	1.014	3.265	2.619
post-test	8							
Control	4	9.250	0.500	0.250	2.000	1.014	4.000	2.619
Experiment	4	8.375	1.109	1.229	-0.482	1.014	-1.700	2.619
pre to post Difference	8							
Control	4	2.500	1.000	1.000	2.000	1.014	4.000	2.619
Experiment	4	1.750	1.259	1.583	-1.129	1.014	2.227	2.619