2023

SEQUENCING OF EXTENDED REALITY WELDER TRAINING

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by

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A DISSERTATION

Presented to the Faculty of

The College of Education and Human Services

Department of Educational Studies, Leadership, and Counseling

at Murray State University

In Partial Fulfillment of Requirements

For the Degree of Doctor of Education

P-20 & Community Leadership

Specialization: Postsecondary

Under the supervision of Associate Professor Dr. Randal H. Wilson

Murray, KY

May 2023

Acknowledgment

I want to express my appreciation and indebtedness to Dr. Randal Wilson, Dr. Emma Miller, and Dr. Sid Martin, who served on my committee, mentored, and guided me. My gratitude and thanks are also extended to the many professionals who offered support, wisdom, guidance, and encouragement. Thank you to Dr. Cedric Bradley for encouraging me multiple times to pursue this degree. To my dear friend, Ms. Teresa Lampe, thank you for taking this journey with me. Your friendship has been a sisterhood that is a rare find.

Several people were instrumental in this study. Dr. Jonathan Woodward, I am grateful for your idea. Dr. Douglas Donohue, thank you for helping me with the design and analysis. Dr. Adam Swanson, thank you for your guidance. Dr. Erin Riggins, thank you for helping me understand workforce training, providing input, and introducing welding experts. I am indebted to Mr. Ronnie Penton, who was with me from day one as my welding expert, and Mr. Jefferson Reid, who wore many hats, including welding expert, project manager, adviser, and leader. I am grateful to Mr. John Jones, Mr. Luke Overstreet, and Mr. Kimothy Lizana for your welding expertise. I am beyond humbled by the selflessness you each exhibited.

Finally, to my family, my thanks and love. To my husband, Doug, your encouragement made what seemed impossible to the woman you married a reality. I am grateful to God for you. To my children Michaela, Dakota, and Savannah and my granddaughter Natalie, I hope I have encouraged you to view learning as a never-ending journey - "your turn!".

Abstract

This study used a quasi-experimental design to evaluate the efficacy of integrating XR welding simulations into traditional training programs. The performance outcomes of participants were assessed by an independent American Welding Society (AWS) Certified Welding Instructor (CWI). Participants were evaluated using the NCCER Performance Accreditation Tasks evaluation. After 20 hours of training, the participants used a traditional welder to perform a vertical 3F weld on a steel weld coupon. Three treatment groups were used to evaluate the sequence of extended reality welding simulators in a traditional welding program. Results indicate that sequencing XR practice before live welding did not significantly differ from traditional welding. However, there was statistically significant evidence that practice on an extended reality simulator after training on live welding equipment had a negative impact on performance outcomes.

Keywords: extended reality, welding simulation, virtual reality, welding training

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Chapter I: Introduction

Context

Welding education is in high demand because of the global workforce shortage of skilled workers (Holzer, 2022). This challenge is exacerbated by equipment costs and materials consumption (Chan et al., 2022). Furthermore, the COVID-19 global pandemic illuminates the need for innovative workforce training and development solutions, as many welding programs were halted due to in-person training constraints (Chenarides et al., 2020). One challenge with remote welding instruction is that it is impractical to duplicate the traditional model in an online environment due to skill, specialized equipment, and safety concerns. While lessons can be recorded or streamed synchronously, the practicality of learning to weld using distance instruction requires adopting different strategies and practices (Piotrowski & King, 2020; Trust et al., 2021).

Additionally, the cost of training welding students continues to grow. Equipment and materials costs are two of the most significant expenses. Immediately following the 2020 pandemic, supply chain disruptions resulted in unfillable equipment orders and unpredictable supply delivery. Also, the price of goods increased as predicted by the supply-demand curve model, which states that the price of goods rises when the demand far exceeds the inventory and production of the supply (Chan et al., 2022).

Further challenges include labor shortages and the need for more trained workers to employ as welding professionals (U.S. Bureau of Labor Statistics, 2022). Therefore, the utility and practicality of continuing to train and develop welding talent in the traditional classroom manner are falling short of meeting the needs of manufacturers. Furthermore, there is a significant time investment. The National Center for Construction and Engineering Research

(NCCER)'s welding I training program requires over 300 hours of training (NCCER, 2015). With supply chain needs, material disruptions, and time constraints, exploring alternative models may offer relief.

One potential solution is using Extended Reality (XR) welding trainers. While both augmented and virtual welding technology have been used for several years, the technology continues to advance. Present-day XR welding simulators have transitioned from devices with long lag times and unrealistic graphics to equipment that approaches the authentic welding experience (Aguinas et al., 2001; Lee, 2010; Price et al., 2019). Data on extended reality welding simulator performance in training can become obsolete as welding technology evolves.

A review of the present literature indicated that more research is needed to illuminate the efficacy of XR training protocols. Wells and Miller (2020) conducted a study with 70% of the participants with prior welding experience. The data indicated that students using the virtual welding simulators did not significantly differ in performance compared to traditionally trained students using live, traditional welding machines. One exciting finding by Wells and Miller (2020) was related to their methodology for integrating virtual welding simulators into training. Wells and Miller (2020) tested three protocols, with the data demonstrating that the group training virtual 100% of the time outperformed the 50% traditional and 50% virtual welding group. The researchers recommended that additional studies evaluate the sequencing of virtual welding simulators in entry-level welding training (Wells & Miller, 2020).

Byrd et al. (2015) argued that XR equipment is effective with basic welds. Additionally, Byrd et al. (2015) indicated that welding simulators could successfully assess entry-level welds but need help assessing advanced welds. While assessment is one portion of the workforce force development cycle, proper training is essential to skill attainment. Welding students must receive adequate training before testing. The data were inconsistent regarding the success of XR welding simulators in providing skill attainment. Whitney and Stephens (2014)'s declassified Australian government report called for a methodology of integrating XR welding simulators supported by research.

Purpose of the Study

This study investigated the efficacy of integrating XR welding simulators into traditional training programs. During the COVID-19 pandemic, the delivery of remote instruction was often the only option available. Because welding requires equipment, materials, and safety protocols, traditional welding training was impractical in a distance learning setting. Consequently, a southern regional college invested in XR welding training technology to support remote learning and provide innovative workforce training. This study evaluated whether the integration and sequencing of XR welding simulators into the curriculum significantly impacted student achievement.

Significance of the Study

XR welding simulators used in welding instruction are a topic of interest for employers seeking qualified, skilled welders to employ. The estimated time to train new welding professionals is 300 instructional hours for level one mastery (NCCER, 2015). With the evolution of technology, virtual machinery, and artificial intelligence, virtual welding technology can simulate real-world challenges. However, data supporting XR welding training in welding instruction as a viable alternative to traditional welding training exposes a gap in research.

The present body of knowledge has a significant variance in research purpose, testing, and outcomes. The effectiveness of XR welding simulators can vary based on the complexity of the welds (Byrd et al., 2015). The success rate of virtual welding simulators in determining the quality of complex welds is not reliable, according to Byrd's (2015) study. One potential benefit identified in Byrd's (2015) study suggests that virtual welding simulators can assess entry-level skills successfully.

When evaluating the effectiveness of XR welding training, Wells and Miller (2020) did not control for the prior experience of welding students. They used a sample with 70% of participants having previous welding experience. The study results supported that students trained in Gas Metal Arc Welding (GMAW) using virtual welding simulators did not significantly differ in performance assessment from traditional welding training groups. Wells and Miller (2020) found that using three protocols for testing yielded an area for further research because the data demonstrated that the 100% virtual welding protocol group outperformed the group trained 50% of the time with virtual welding simulators. The researchers recommend additional research evaluating the sequencing of virtual welding simulators in entry-level welding training (Wells & Miller, 2020).

This study illuminated the body of knowledge on the efficacy of XR welding simulations in training and student performance in welding trainer programs, as Byrd (2015) recommended. Additionally, this study built upon Wells and Miller's (2020) recommendation to further research and advance their finding on virtual training sequencing's impact on student skill attainment.

Theoretical Framework

Connectivism is a constructivist approach that places the learner at the center of skill attainment and knowledge acquisition. From this central hub, the learner accesses multiple paths to curate information. Connectivism considers performance systems as a hybridization of workers and technology tools. Connectivism provides the theoretical foundation for this study's examination of XR technology for welding training and simulation (Siemens, 2005). Through the connectivism lens, this study explored system optimization in sequencing training and skills attainment.

Additionally, this study relied upon the Dynamic Interactive Virtual Environments (DIVE) taxonomy that Blom and Beckhaus (2013) identified. In this taxonomy, like connectivism, there are multiple paths of experience. DIVE asserts that experiential learning occurs in a virtual environment when continuous interaction, object manipulation, and sensory feedback are incorporated (Blom & Beckhaus, 2013).

Research Questions

The primary research question was, "Does the sequencing of welding practice with extended reality (XR) training equipment affect student welding performance as measured by the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position assessment?". The following research questions were used to illuminate the primary question.

Research Question 1. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice in addition to traditional welding instruction?

H_0: $\mu_T = \mu_{XRC}$

H_A: $\mu_T > \mu_{XRC}$

Research Question 2. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction?

H_0: $\mu_T = \mu_{XRB}$

H_A: $\mu_T > \mu_{XRB\backslash}$

Research Question 3. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_T = \mu_{XRF}$

H_A: $\mu_T > \mu_{XRF}$

Research Question 4. Do welding students who receive XR practice before traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_{XRB} = \mu_{XRF}$

H_A: $\mu_{XRB} > \mu_{XRF}$

Definitions, Terms, and Abbreviations

Augmented Arc: Miller Welds extended reality welding simulator

Augmented reality: an environment in which digital overlays enhance the live experience

AWS: American Welding Society

Coupon: a small piece of metal used for welding practice and testing

Extended reality: a term that includes all reality plus technologies, including virtual reality, augmented reality and mixed reality

FCAW: flux core arc welding

GMAW: gas metal arc welding

GTAW: gas tungsten arc welding; synonymous with TIG welding

HMD: head-mounted display; wearable technology for human integration into virtual environments

Live weld: traditional welding in real-time with and creates a physical weld

Mixed reality: a hybrid reality that integrates digital objects into the real world that can interact with the physical world

Remote learning: instruction when the student and teacher are physically separated

SMAW: shielded metal arc welding or stick welding

Stick: the electrode used in SMAW

Strike the arc: the action of striking a welding plate with an electrode

TIG: tungsten inert gas welding; requires two hands; uses a foot petal

Traditional welding instruction: teaching with live industry equipment without the use of extended reality (XR) technologies

Virtual reality: an immersive digital environment that excludes the physical world

Workforce training: an umbrella term for developing industrial skills

XR: an abbreviation for extended reality

XR practice: the dedicated use of logged class time to practice a specific weld type using an extended reality welding simulator

XR welding trainer: a generic term for extended reality machinery used to promote welding skill acquisition

Summary

This chapter highlighted existing literature about integrating XR welding trainers into workforce training. The studies in this chapter indicated a need for research on integrating XR welding technology into welding training, the sequencing of XR welding simulator technology into instruction, and the success of learners that use the XR simulators for welding training. This research was necessitated by the welding worker shortage and the advancement of XR technology as a potential solution to augment welding training programs.

Chapter II: Literature Review

Extended reality (XR) has served workforce training and development since the 1990s. XR trainers and simulators for specialized skills such as plane and tank operations have helped with military training and operations (Aguinas et al., 2001; Acosta et al., 2019; Baxter & Hepplewhite, 1999). Healthcare and medical services also benefit from the use of XR technologies. Using XR simulations benefits patient safety, immersing the learner in unpredictable emergencies and simulating patient assessment (Teixeira & Pimentel, 1993; Zajtchuk & Satava, 1997). Across various industries, XR technology supports training and simulations in safety protocols, disaster mitigation, and evacuation planning (Dobrzański et al., 2008; Feng et al., 2018).

Continuous improvement initiatives, labor shortages, supply chain issues, and technological advances are some factors that influence employment skills in demand (Holzer, 2022). Workforce development has embraced using XR tools to mitigate the workforce skills gap (Lester & Hofmann, 2020).

While virtual reality (VR) and augmented reality (AR) training tools reside within the broader definition of XR technology, they are not synonyms. A key difference is the immersion level of the technology. A fully immersive environment is a VR environment, while an AR environment is a physical environment enhanced with virtual overlays and digital components (Lester & Hofmann, 2020).

As XR technology advances, welding training technology has become available. Welding equipment manufacturers are embracing and selling XR simulators for welding instructional tools to assist workforce development (Huang et al., 2020; Lincoln Electric, n.d.; Miller Electric, 2022; Stone et al., 2011). However, the variance of features associated with XR welding trainers makes establishing the technology's merit challenging.

Best practices for integrating welding XR simulators are in the early stages of development. There is a need for evidence-based methods for optimizing XR tools as instructional technology. The literature review will explore the feasibility of XR welding simulator technology adoption and the supporting evidence for best practices in XR welding simulator training.

Feasibility of Adoption of XR Simulators in Welding Training Programs

Receptiveness

Industries desire innovative solutions to address gaps in workforce training and development. There are commercially available welding training tools to support workforce training and education. Virtual training devices for industrial work are presently being used in workforce development (Acosta et al., 2019; Doshi et al., 2016; Hillers et al., 2013; Lee, 2010; Srinivasa et al., 2020; Wang et al., 2020; Whitney & Stephens, 2014).

Training with XR has been explored for years for welding training (Byrd, 2014; Byrd et al., 2015; Dong et al., 2018; Lee, 2010; Stone et al., 2011; White et al., 2010). However, the broad-based use of XR welding simulation training solutions for workforce training has some resistance from the welding training community (Papakostas et al., 2021). One concern is the need for more authenticity of the XR welding training technology and the problem this creates with knowledge transfer. Another concern cites instructor preparation and training. Direct training to integrate the instructional technology into the course builds confidence and interest in integrating the tool (Trust et al., 2021).

Need

Welding is projected to grow in demand at 8% annually in the USA. Current models suggest 450,000 welding jobs will be vacant by 2030 (U.S. Bureau of Labor Statistics, 2022). The growing deficit between demand and availability of a skilled welding workforce will lead to a declining industry. Worker shortages exacerbated the critical need for qualified welding staff (Chan et al., 2022; Fortune Insights, 2021; U.S. Bureau of Labor Statistics, 2022). Baby Boomer retirements coinciding with a decrease in population made recruiting and training individuals to become welders difficult (Holzer, 2022).

In the 2020s, the skills gap in the workforce led to an industry with high demand and a low supply of skilled welders to employ. The occupational need for welding remains critical (Fortune Insights, 2021; Holzer, 2022). Workers are asked to produce without proper training. One explanation for using an untrained labor force was the need for more available instructors. Some businesses have employed workers to weld without an apprenticeship or formalized training. Lack of formal training often leads to injuries and safety risks (Fortune Insights, 2021).

Economic Disruptions

The welding labor shortage has adverse outcomes for production. Businesses need to meet the supply-chain demand. Financial penalties are attached to delivering goods. Time-based contractual obligations have financial penalties for delayed fulfillment of contractual obligations (Fortune Insights, 2021; Miller Electric, 2022). Additionally, the disruption of the COVID-19 pandemic exposed the need for more flexibility in the supply chain. Many businesses did not invest in innovation and automation (Chenarides et al., 2020).

Culture and Historical Background

People learn within the context of their culture (Committee on Developments in the Science of Learning, 2018). The history of technology integration provides a cultural context for technology adoption and training. Industrialization and technology innovations provide insight into circumstances that fostered resistance toward technology adoption.

The first modern revolutionary wave was the original industrial revolution (1R) which began with the steam engine. The use of steam power was a catalyst for the growth of urban factories from the mid-1700s to the mid-1800s (Moll, 2021; Philbeck & Davis, 2019). This revolution changed society in multiple ways. People moved from rural lifestyles to city centers. The reliance on family and community was replaced with dependence on employment as the new working generation moved to cities (Benokraitis, 2011; Seccombe, 2017). Once in these urbanized centers, people encountered inadequate housing and poor working conditions, which led to health consequences. Long hours and poor sanitation threatened the quality of life for factory workers. The growth of manufacturing led to the need for more transportation infrastructure. For ordinary workers, life was dangerous and unhealthy (Ferris & Stein, 2014; Moll, 2021; Seccombe, 2017).

The second wave of industrialization (2R) occurred from the 1870s to the 1910s (Moll, 2021). This second revolution widened the gap between industrialized and non-industrialized nations. An emphasis on efficiency in processes was a hallmark of business models in the post-modern era (Moll, 2021). The 2R established the worker as a process, simplified to its marginal task, that used technology as a work aid. Deskilling led to workers becoming single-task machine operations. The consequence was that workers only needed the skill to do a handful of repetitive tasks with little challenge or autonomy (Braverman, 1974).

The continued growth of technology ushered in the third industrial revolution (3R), which occurred from the 1960s through the early 2000s (Philbeck & Davis, 2019). The digital information age includes a synchronous reality that is not reliant on proximity.

The advancement of ARPANET, a military system that became the backbone of the internet infrastructure, was a significant development (Defense Advanced Research Projects Agency [DARPA], n.d.; Moll, 2021; Phillips, 2000). After ARPANET technology was repurposed for public use, Sir Tim Berners-Lee developed the web-addressing system known as the World Wide Web (CERN, n.d.). The internet changed the relationship between people and machines in ways that were dramatically different from previous revolutions (Chen et al., 2005). The reliance on technology for daily living surged and became a social norm. Technology allows workers to collaborate remotely. The workforce shifted from repetitive work to accessing tools that engaged thinking skills, such as web communications and smartphones (Geser, 2006).

During this dramatic change, virtual gaming became a part of mainstream society (Zajtchuk & Satava, 1997). Worker training adopted these technologies to provide workforce training through simulation. Workers participated in virtual situations in this new revolution that fostered critical thinking (Dalgarno & Lee, 2009).

The fourth industrial revolution (4R) continued to move the needle away from the rationalization of work as task-driven and towards technical knowledge and specialization. Quantum computing, artificial intelligence (AI), and bioengineering represent 4R technological advancements (Liu et al., 2014; Philbeck & Davis, 2019; Xu & Moreu, 2021). There are emerging ethical challenges as the line between humans and machines becomes a single workforce. Specific examples of blurring human agency and digitized systems include the internet of things (IoT), AI decision systems, and XR training systems. These 4R technologies integrate neuro-technologies that emulate human capabilities (Philbeck & Davis, 2019).

The 4R integration of artificial intelligence systems that can learn autonomously challenges the superiority of human thinking and accuracy. These knowledge advancements create uncertainty about the value added by human workers as machines develop decision and support systems that rival human capacity. In the 4R, the relationship between humans and technology is vacillating between benefitting innovation, new skill demands, and the retooling of workers (Gibson & Pick, 2000; Philbeck & Davis, 2019; Whitchurch & Constantine, 2008).

The 2019 global pandemic exposed a knowledge gap in remote working and learning. Because of the regulations for social distancing, education via remote communication and collaboration was necessary. This dramatic change in how people are taught requires a new methodology for instruction that is effective and adaptive (Piotrowski & King, 2020; Trust et al., 2021). As andragogy is developed to strengthen the best practices of XR technology in instruction, it is essential to value the historical experiences and the shifting skills needs between revolutions.

Historical patterns demonstrate that innovation leads to adjustments in workforce skills (Chenarides et al., 2020). Widespread XR adoption may lead to mistrust and fear of the XR technology application's process and validity (Caruth & Caruth, 2018; Trust et al., 2021). Neglecting to manage and acknowledge widespread concerns about XR welding simulator instruction can threaten the adoption of the XR training technology. Ivy Tech instructors, a community college rolling out the VRTEX trainer by Lincoln Electric, experienced initial resistance but could adapt once the stakeholders witnessed the positive outcomes for student learning post-implementation (Evans, 2007).

Considerations for Establishing Best Practices

Quality Indicators of XR Training Technology

Technical authenticity. Authentic XR instructional experiences rely on learner immersion (Chan et al., 2022; Lee, 2010; Liu et al., 2014). In the 1990s, the early stages of XR development were underway. During this time, VR struggled with pixelation, lags, and delays, undermining VR as an authentic immersion experience. The lag time between movement and response, combined with the low-quality, cartoonish look of the graphical user interfaces (GUI), has hindered the full integration of VR into teaching and learning (Aguinas et al., 2001).

Congruency with Live Welding. Practical XR training must consider the student's skill level when characterizing the welding training experience as genuine. Price et al. (2019) found that experienced welding students dismissed virtual welding simulators for training because the XR system did not provide a realistic experience that matched the performance of live welding. To achieve immersion and authenticity, the XR illusion should be without error or interruption. There should be real-time movement between scene changes in the virtual environment (Aguinas et al., 2001). Moreover, Lee (2010) supports that XR welding trainers should have haptic, audio, and visual feedback to create a realistic weld experience.

Price et al. (2019) suggest that XR welding technology gains realistic qualities by adhering to intuitive navigation, real-time reactions, and lag-free scene changes. Lee (2010) supports the assertion by Price et al. (2019) that realistic XR experiences can be undermined by lag time and poor speed. Lee (2010)'s study was conducted onsite at Korean shipbuilding companies. Lee's (2010) findings suggest that virtual paint sprayers earn poor marks from participants when the system experiences delays.

Present-day XR welding technology often includes tactile feedback and simulates force.

Some XR welding trainers provide temperature, friction, speed, and tension feedback. Welding requires a worker to understand and respond to stress, drag, mass, and surface movements. Immersion helps the learner develop muscle memory that supports welding tasks (Lincoln Electric, n.d.; Whitney & Stephens, 2014).

Kramer (1995) asserts that not all feedback is helpful or necessary. Audio feedback can be distracting and without merit for some tasks. The recommendation from Kramer (1995) is to incorporate audio when it enhances the learner experience. This assertion is controversial. For example, Teeravarunyou and Poopatb (2009) study divided sixty university engineering students into two groups. The first group did not receive any auditory feedback from the welding simulator. The second group was provided auditory feedback and guidance on speed and direction. When the two groups underwent live welding assessments, the feedback group significantly outperformed the no-feedback group when mean scores were compared. Additionally, the feedback group approached the traditional values desired by the welding simulator's tolerance settings. This finding suggests that feedback in speed and direction may have merit.

In addition to audio feedback, visual information may improve outcomes in XR welding training. Hillers et al. (2013) analyzed the success of graphic details in XR welding training. The results suggest that training was more effective when a helmet with an XR-assisted camera could provide the target's visible location before striking the arc and beginning the weld. This study suggests that the instructional process of using XR welding simulators in training can significantly enhance proprioception and support the live welding environment (Hillers et al., 2013).

Feedback must be timely and avoid lag and delays. Latency interferes with the real-time integration of the virtual experience (Kramer, 1995). Latency in an XR system should be undetectable. A lag time of half a second or less on sensory feedback is a typical recommendation (Hawkes et al., 1995; Kramer, 1995). Brunnström et al. (2020) recommend a maximum lag time of .03 seconds but concede that humans will tolerate a half-second delay. Hawkes (1995) asserts that poor lag time update rates and variable update rates are problematic. Both lag time and inconsistency appear to impact the user experience negatively. Wilson (1997) concurs with Hawkes (1995) that latency is difficult. However, Wilson's (1997) study focused on how a delay in response to user movement or input can impact user safety.

Realistic Welding Parameters. Emulating the welding type and weld position parameters is critical to creating a realistic XR welding simulated experience. Realistic XR welding machines support welding training, motivation, and student engagement (Acosta et al., 2019; Bowman & Hodges, 1999; Brunnström et al., 2020; Dong et al., 2018; Hawkes et al., 1995; Papakostas et al., 2021; Shankhwar et al., 2022). Researchers have studied parameters that impact the weld experience and quality. The variance of parameters necessitates an intelligent, responsive, virtual system that adapts to variance and essential welding variables to maximize human performance. Three parameters comprise weld quality: arc, speed, and angle (Chan et al., 2022; Jeyaganesh et al., 2021; Liu et al., 2014; Price et al., 2019; Shankhwar et al., 2022; Whitney & Stephens, 2014). Whitney and Stephens (2014) also identified the critical elements that benefit from XR welding training feedback: the welding gun position, movement, speed, angle, and dynamic adjustments.

Ease of Use. Ease of use and perceived value are two critical components of technology acceptance according to the Technology Acceptance Model (TAM). Navigation and a userfriendly interface that requires minimal training are essential elements of a virtual simulation (Dobrzański et al., 2008; Lester & Hofmann, 2020). Papakostas et al. (2021) studied XR acceptance using the TAM to assess quality and enjoyment as factors related to ease of use. The study's results support that quality and enjoyment predict ongoing use (Papakostas et al., 2021). Similarly, Price et al. (2019) suggest XR training dissatisfaction dissuades further use.

Lester and Hofmann (2020) quantify ease of use differently than Price et al. (2019). They assert that preparation is a vital factor in ease of use. The research findings suggest that the instructor and the student benefit from preparation and training as an investment in ease of use. Trust et al. (2021) further strengthen preparation and training as factors in success. Trust et al. (2021) found that awareness of using XR before integrating the XR technology into the course instruction was the most reported barrier to integration.

Feedback. Price et al. (2019) analyzed experienced welding professionals' responses to XR welding training. The participant feedback regarding welding speed, contact tube to work distance, and work angle indicated that students with prior welding knowledge disliked the virtual welding simulators. The participants reported that the feedback provided by the XR machines had limited tolerance for technique variances, which created false failing results. The feedback can inaccurately report an invalid weld if XR welding assessments are too narrow or limiting a successful weld to a single technique. The Lincoln VRTEX 360 used in the study was cited by the participants with experience as inaccurate due to the welding techniques the machine would record favorably.

In addition to technique feedback, research findings indicate that instructor communication can support learning. Whitney and Stephens (2014) found that the instructor's presence was attributed to the timeliness of feedback and coaching. This finding was similar to

Lee (2010), who documented increased communication between the instructor and the student as a potential success factor.

Mechanical feedback can be critical in XR welding technology. Haptic feedback can simulate tension, heat, and friction (Lee, 2010). The closed-loop motor learning theory supports the need for this type of quality feedback. In the closed-loop theoretical perspective, the assertion is that learning relies on sensory feedback to achieve mastery (Adams, 1971). This theoretical perspective supports the findings by Lee (2010) that XR welding training programs benefit from haptic feedback. Further findings by Lee (2010) support additional research to address a knowledge gap cited by the Australian government in a declassified report. This report indicated that research studies are not determining which elements or combinations of strategies are necessary to deliver a quality virtual welding training experience (Whitney & Stephens, 2014).

Attention, Relevance, Confidence, and Satisfaction. The ARCS model is focused on motivational design. This model's motivation components are attention, relevance, confidence, and satisfaction (ARCS) (Keller, 2010). In Acosta et al. (2019), the experimental group in which participants were trained for the first seven weeks of instruction using XR welding technology reported significantly greater attention and confidence scores than the traditional group that used live welding equipment for the first seven weeks. Conversely, the conventional group had a higher satisfaction rating. Relevance did not have a statistically significant finding. However, the control group did report higher relevancy scores. The study design was quasi-experimental, with a control group using traditional classroom learning without technology for the first seven weeks and the experimental group using technology integration for the first seven weeks (Acosta et al., 2019).

Like Acosta et al. (2019), Texas A&M engineering students with no prior welding experience indicated confidence after using an XR trainer for one hour (Price et al., 2019). Still, there needs to be more research identifying how to achieve positive ARCS scores on all indicators with XR welding technology. Future research may support technology and instructional innovations to establish this congruency.

Efficacy Concerns

Knowledge Transfer. One area of concern with instructional XR is the transfer of knowledge. A Norwegian case study found that training with XR welding technology did not significantly transfer knowledge. The teachers recommended that future use incorporate XR welding simulators that contained simulated sound and heat. Another recommendation was to use XR welding trainers for individual instruction, as their findings indicate that it yielded more positive learning outcomes than group instruction with the XR welding simulators (Karstensen & Lier, 2020).

Assessments. While assessments can offer knowledge transfer evidence, one study found that delayed testing during welding practicums led to confusion. However, students were more successful when tested immediately (Rose et al., 2015). This finding illuminates a challenge to the efficacy of XR training as valid for skill acquisition that the learner retains.

Additional efficacy concerns are related to the level of skill of the learner. Whitney and Stephens (2014) suggest that using XR welding simulators in welding instruction benefits novice welding students performing basic welds, but experienced welding students are unlikely to benefit. The findings note that teaching specialized welding skills needed in military operations did not demonstrate learning when assessed (Whitney & Stephens, 2014). This finding suggests that future research may benefit from the customization of XR welding simulation tolerances and strategies for specialty welding.

Length of Research. An additional concern is a need for a broad research consensus. The use of an XR welding trainer is frequently used as a treatment for less than a day before assessing the learning outcomes. For example, Wells and Miller (2020) relied upon one XR welding simulator training session to teach the GMAW 2F weld. The session lasted one hour with a welding trainer and did not support the efficacy of XR technology for welding performance when assessed by certified welding instructors (Wells & Miller, 2020).

Taxonomies for XR Training Deployment

Framework for Affordances of Virtual Assisted Technologies. Steffen et al. (2019) developed a research-based framework for using XR in teaching and learning. This framework is built on the premise that XR experiences differ from physical reality; therefore, user acceptance and motivation vary between XR and physical reality. The framework identifies four affordances for the adoption of XR technology in education. The first affordance is that the XR enables the experience to overcome or negate the undesirable components of the physical reality. The second affordance in this model is that the positive aspects of physical reality are augmented and extend the positive qualities of physical reality or provide information that is not easily gathered in physical reality. The third level of the framework is pragmatic. The virtual elements included in the XR experience should be limited to those valuable to the outcome goals. The final affordance in this taxonomy is that the user can experience hypothetical, futuristic, or historical situations or objects that are not readily accessible in physical reality (Steffen et al., 2019).

Dynamic Interactive Virtual Environments (DIVE). Blom and Beckhaus (2013) studied virtual environments and their dynamic components. The findings support that using combinations of interactions in virtual environments can be used to maximize the user experience. These components include both categories and taxonomies. Blom and Beckhaus (2013) break down dynamic types into five categories: interaction, dynamic elements, dynamic interactions, interactive dynamic components, and dynamic interactions with functional features. DIVE's taxonomy includes object interaction, manipulation, navigation, and pathway determination. Scene design includes sensual elements, haptics, and abstract concepts within the dynamic component. DIVE incorporates interactive dynamic features with continuous interactions, a set of intervals, and a set of actions (Blom & Beckhaus, 2013). This taxonomy supports XR welding simulators with haptic feedback, immersion, and authentic engagement.

Skill Attainment Theory. Ackerman's theory of skill determinants specifies that task consistency, complexity, and the amount of practice are the three major components of learning a skill (Ackerman, 1988). Consistency is a critical element of learning and is supported by Ackerman (1988) and the closed-loop theory of motor skill acquisition. Motor learning theory supports the attainment of skills through feedback and experiences in the training and learning environment. Motor learning theory asserts that skills-based learning is contingent on input and practice. This theoretical perspective supports using XR welding trainers for practice (Adams, 1971).

Systems Theories. Systems theories take a holistic approach and view the culmination of various process parts as a system (Whitchurch & Constantine, 2008). This theoretical perspective supports self-motivation as a crucial element of learning (Papakostas et al., 2021). Because the system theoretical perspective asserts that interaction with the environment is necessary to construct meaning, it is compatible with the closed-loop's dependency on sensory feedback (Adams, 1971; Whitchurch & Constantine, 2008). The Technology Adoption Model supports the emphasis on sensory input and self-motivation, which gauges user acceptance when examining value, ease of use, and quality (Papakostas et al., 2021).

Interaction is the heart of the ecological approach to learning. This approach is a system theory that views the person and their environment as an interactive system. The ecological theoretical approach relies on affordances, which are the perceived suitability of a tool or environment for the individual (Gibson & Pick, 2000). Additionally, Gibson and Pick (2000) focus on the second essential component of the ecological theory's view on information transmission through action. As part of this approach, learning engages the senses and uses exploration and feedback. Exploring responses to various scenarios provides information and learning affordance when the exploratory testing yields consistent, predictable actions and results (Gibson & Pick, 2000).

This theoretical perspective can be used to understand the concern expressed in Lee's (2010) shipbuilding study, in which participants voiced concerns about the inaccurate air compression of the virtual paint spraying trainer. Additionally, this perspective provides a lens for the active learning necessary to establish muscle memory, physical skill, and responsiveness to feedback needed for welding.

Connectivism. Experiences as patterns are a crucial facet of the connectivist learning theory that emerged in 2004. Connectivism integrates the demands of human performance from the digital age and the speed at which organizations must adapt to these changes. The connectivity paradigm posits that knowledge is acquired through multiple pathways (Siemens, 2005). Connectivism is compatible with the ecological perspective of systems theory that bundles the human and the machine as a learning system. Connectivism, like ecological theory, focuses on the human as one half of the learning loop. However, connectivism replaces the device with the organization.

Proponents of the connectivism theory assert that technology determines how we interact, what options are available, how our brains are wired, and how we think, learn, and adapt (Siemens, 2005). Connectivism supports the use of multiple pathways of feedback available in XR welding simulations. Connectivism also offers a model for the merger of the person as an organizational asset when connected with performance machinery. This perspective suggests that concerns by experienced career welding professionals should not be dismissed but explored further for merit, opportunity, and workable solutions.

Welding Overview

Fundamentally, welding is a process that uses heat to join two metal or thermoplastic materials. Mastery welding includes performing various welds, tolerating harsh working conditions, and using safety equipment properly (Chan et al., 2022). ARC welding uses electrical currents that heat into an arc. Heat fuses metals (American Weld Society, 1976; Chan et al., 2022; U.S. Bureau of Labor Statistics, 2022).

Traditional welding instruction is typically designed to allow the students to practice skills, receive feedback, and complete assessments (Whitney & Stephens, 2014). Practice and feedback are critical components of live weld mastery. Instructor feedback is a valuable element of the learning process. Instructor feedback can include coaching before, after, or during the welding session (Whitney & Stephens, 2014).

Methods

The primary welding methods of arc welding include shield metal arc welding (SMAW), gas metal arc welding (GMAW), flux-cored arc welding (FCAW), and gas tungsten arc welding

(GTAW). SMAW is one of the simpler welds in which an electrode strikes a plate to activate the arc. The electrode is commonly referred to as a stick and contains shielding gas that combusts from the exterior coating of the electrode (American Weld Society, 1976).

In SMAW, the person welding must ensure the electrode is not fractured or damaged. Electrodes must be carefully stored, protected from moisture and humidity, and not cracked during use (American Weld Society, 1976; Rampaul, 2003). The beginner student often uses too much current in this style of welding (Rampaul, 2003).

GMAW differs from SMAW because the shielding gas is fed through a cylinder instead of contained in the electrode covering. GMAW welds are often used, requiring attention to the current, arc voltage, and arc speed. In FCAW, a wire filament is continuously fed and heated as it is applied to create a seam on a metal plate.

GTAW uses a shielding gas that is inert and nonflammable. The shielding gas assists with protection and heat transfer and does not require a filler metal (American Weld Society, 1976; Rampaul, 2003; Weman, 2012). While it provides a high-quality weld, it also requires more training time because of the degree of manual dexterity and coordination it demands (American Weld Society, 1976; Weman, 2012). GTAW welding is a cleaner weld (Rampaul, 2003). GTAW often involves a foot pedal and requires the person welding to stop and start (Liu et al., 2014).

Positions

Welding positions are identified with a number and a letter. The letter F indicates a fillet weld that joins T or perpendicular surfaces. A groove weld is a filler to adhere pieces together (Whitney & Stephens, 2014). The primary plate welding positions include flat (1F), horizontal (2F), vertical (3F), and overhead (4F) (Rampaul, 2003; Whitney & Stephens, 2014).

Human Performance Parameters

Specific skills are needed to advance as an employed welder. Vital skills include mathematical reasoning, hand-eye coordination, physical strength, and spatial awareness (U.S. Bureau of Labor Statistics, 2022). Variables to master the skill of welding include gun speed and voltage (White et al., 2010). Working with welding equipment requires one to be responsive to visual, auditory, and haptic feedback to create quality welds. Adjustments are needed throughout the welding process. An experienced welding professional is likelier to use sparks, sounds, and the feel of the welding gun to create the weld (Whitney & Stephens, 2014).

Additionally, manual dexterity is an essential skill for welding. A correlation between dexterity and welding performance was established to indicate future welding success (Byrd et al., 2015). Byrd's (2018) study used manual dexterity tests to predict which candidates would be best for welding programs. The study used simple welds to evaluate candidates. The survey results indicate that manual dexterity is a valuable predictor of simple weld performance. An interesting finding in this study suggests that some students saw their manual dexterity improve over time. Byrd et al. (2018) found that after using XR welding trainers, some participants realized improvement in manual dexterity.

Parameters by Weld Type

GMAW and P-GMAW. The parameters necessary to optimize the GMAW welding process include wire feed rate, arc stability, and the burn-off rate of metal filler into the weld pool. The speed of the current is proportional to the wire feed rate (Palani & Murugan, 2006). Optimization of welding can vary depending on the welding type. In pulsed GMAW (P-GMAW), the current is alternated to control heat. The current, the welding speed, and the wire feed rate are critical for P-GMAW welding (Jeyaganesh et al., 2021; Palani & Murugan, 2006).

Jeyaganesh et al. (2021) analyzed the Taguchi parameter optimization method and Grey relational analysis.

The findings support that the wire feed rate, weld current, and weld speed are critical for optimizing tensile strength. Palani and Murugan (2006) also examined the weld current by considering the variability between the base and the pulse currents. Palani and Murugan's (2006) findings support that pulsed currents require a higher wire feed rate than base currents. These studies indicate that the feed rate can vary depending on the type of GMAW weld, the current, and the feed rate of the wire (Jeyaganesh et al., 2021; Palani & Murugan, 2006).

SMAW and GTAW. With the absence of shielding gas, SMAW steps require the user to have a continuous arc length, a travel speed that creates a quality seam, and an electrode angle that makes the appropriate contact angle (Shankhwar et al., 2022). GTAW parameters rely upon the weld style and whether it is a flat or pipe weld. GTAW welding's parameters in flat welds include the wire feed rate, the contact to work distance, the working angle, and the travel angle (Chan et al., 2022). Essential pipe weld variables include weld speed and current (Liu et al., 2014).

Typologies of Extended Reality Welding Trainers

Augmented Reality (AR) Welding Trainers

AR trainers use overlays and virtual objects in a virtual environment (Lester & Hofmann, 2020). One challenge with this type of welding simulation is that it requires the participant to wear a head-mounted display (HMD) (Chan et al., 2022). Present HMDs have advanced the immersion experience to a high degree of acceptance of the virtual experience while simultaneously disconnecting from the natural world experience (Chan et al., 2022; Radianti et al., 2020).

Doshi et al. (2016) examined the impact of XR simulators in welding training on spot welding. AR technology assisted with the placement of spot welds and was demonstrated across a range of welds at an automotive manufacturing facility. Using projection, the AR system could help with precision and accuracy (Doshi et al., 2016). The feedback from the projection system supported the worker with the task at hand. A similar observation was documented in an AR welding study that evaluated the use of AR overlays, which were augmented with feedback. Training participants who used more-overlay feedback tended to perform better (Stone et al., 2013).

Virtual Reality (VR) Welding Trainers

VR technology relies upon navigation, interaction, and immersion (Vince, 1998). Immersive welding trainers can benefit from an entirely virtual world that does not require materials and supplies (Chan et al., 2022). The immersion of a person into a wholly virtual world and experience is a fundamental difference from AR, which overlays virtual elements onto a physical environment (Chan et al., 2022; Radianti et al., 2020).

Recommendations

Equipment

XR welding simulators rely upon displays to help the user visualize the weld pool and arc (Evans, 2007). XR welding simulators use displays to augment feedback (Porter et al., 2006; White et al., 2010; Whitney & Stephens, 2014). Displays can be panel displays or head-mounted displays (HMD). The quality of the display influences the user experience. The ideal user experience should reach a level of realism that allows the learner to disconnect from the physical world (Chan et al., 2022; Radianti et al., 2020).

Hand controllers engage the learner and allow input (Brunnström et al., 2020; Hawkes et al., 1995; Tanjung et al., 2020). Controllers vary in the method of input. Standard designs incorporate control, hand, finger, or arm movement. A welding gun is the physical controller component in an XR welding trainer. The welding gun feedback to the user can include haptics and sound and even simulate the electrode sticking by incorporating electromagnets (Kobayashi et al., 2001; Whitney & Stephens, 2014). Sound can have auditory feedback that provides coaching or machine sound to emulate a live experience (Kobayashi et al., 2001; Porter et al., 2006; White et al., 2010; Whitney & Stephens, 2014).

Parameters

The variance in equipment and options led Whitney and Stephens (2014) to recommend future research on which parameters or the combination of parameters maximizes performance. Some researchers have suggested critical parameters for XR welding trainers to produce quality outcomes. Shankhwar et al. (2022) posit that authenticity, haptics, and heat generation are necessary for XR welding training. The research on this topic suggests that the user experience with XR welding trainers is enhanced when a machine detects and responds to intentionality (Wang et al., 2020; Xia et al., 2020). Predictive analytics of human trajectory or motion intention is incorporated into the machine's AI (Bowman & Hodges, 1999; Shankhwar et al., 2022; Wang et al., 2020; Whitney & Stephens, 2014).

Authenticity

A realistic training experience is a typical recommendation in welding training research. Dobrzański et al. (2008) and Salas (1998) are proponents of using realistic simulations but assert that there must be a transition to a real-world environment to train fully. The limitations expressed regarding using XR welding trainers are often regarding authentic feedback.

Specifically, narrow tolerances of welding parameters are often cited as areas where XR welding simulators can improve these tolerances to match the actions of veteran welding professionals by using accurate mathematical modeling (Teeravarunyou & Poopatb, 2009; White et al., 2010; Whitney & Stephens, 2014).

Considerations

Experience Level

Evaluating welding performance after practicing with an XR welding trainer has been widely researched. Many studies use novice welding students. However, in Byrd's (2015) study, the XR welding trainer's artificial intelligence software was tasked to identify the novice group from the experienced group. Byrd (2015) found that the XR welding trainer was most successful at identifying an expert welding student from a novice welding student while evaluating the most challenging welds. When performing simple welds, the XR welding simulator software did not efficiently discern between an experienced and a novice welding student (Byrd, 2015). Byrd's (2015) finding aligns with an unclassified Australian government report that considered the efficacy of virtual welding simulator training for the military.

The report concluded that there was evidence suggesting that integrating virtual welding simulators into traditional training using actual welding equipment could assist novice welding students in the learning process. However, the report indicates a diminishing benefit for more experienced welding students. The report findings document the reduced efficacy of virtual simulations in welding training when the student is experienced with live welding (Whitney & Stephens, 2014). Whitney and Stephens' (2014) findings contradict the findings of Erden and Billiard's (2016) study in which an artificial intelligence robotic arm could identify the work of experienced student welders because of their ability to respond to variance in impedances when performing GTAW.

Sequencing of XR Welding Simulators into Traditional Welding Instruction

A limited number of studies have examined the sequencing and timing of XR welding trainer integration into welding instruction. A 2020 study at Iowa State University tested four different instructional modalities for welding. The study contained 101 participants from various majors and varying welding exposure. They were randomly assigned to one of four groups. The four modalities were tested in one-hour individual sessions using the following formats:

- 100% of the hands-on time was on traditional, live welding equipment
- 100% of the hands-on time was on an XR welding simulator
- 50% of the hands-on instruction used an XR welding trainer, followed by an equal amount of time on a traditional, live welding machine
- 50% of the hands-on instruction uses a traditional, live welding machine, followed by an equal amount of time for an XR welding trainer (Wells & Miller, 2020).

The study data did not contain enough evidence to conclude that one of these four modalities is better. The results did not indicate a significant difference between the outcomes when the work products were evaluated by independent American Welding Society (AWS) Certified Welding Instructors (CWI). While not statistically significant, the findings reported that the 100% virtual group performed the best, and the 50% virtual transition to 50% traditional performed the worst. The entirely traditional welding group was in the middle. These finds suggest that research is needed to determine how to integrate XR training into welding for optimization (Wells & Miller, 2020).

Srinivasa et al. (2020) also compared the placement of virtual and live welding in instructional delivery. Like the Wells and Miller (2020) study, real-world and virtual welding exposure was limited to a single session. The researcher had 118 participants assigned randomly to groups. Group 1 completed the first activity on an XR welding trainer and the second on a real-world machine. Group 2 started on real-world equipment and used the XR welding trainers for the second activity. The results support that the group that began on the virtual trainer significantly outperformed the group that started on the real-world machine in procedural questions, concept questions, and engagement. Interesting findings of this study include that engagement increased in both groups during the XR activity, suggesting sequencing may not impact engagement. The statistically significant test performance difference indicated that the XR group initially performed better. The assessment process differed from Wells and Miller's (2020) study, which assessed participants' performance in making a weld. Srinivas et al. (2020) used a traditional question-and-answer paper-based test to assess knowledge.

Instructional Methods

The results of Wells and Miller (2020) and Srinivas et al. (2020) are consistent with the findings of Stone et al. (2013), who conducted an experimental design study using VRTEX 360 welding simulators. The study was on a small sample of 12 men with no prior welding experience. Group 1 was the control group that learned with 100% traditional, live weld instruction. Group 2 was the experimental group that used conventional live welding 50% of the time and the XR simulator 50% of the time (Stone et al., 2013). When evaluating four different welds, the XR group outperformed the traditional group. Stone et al. (2013) noted that the students in the XR group had more practice and interacted with other students than those in the traditional-only group. The results indicate that students who used XR overlays and received feedback had more success (Stone et al., 2013).

Byrd et al. (2018) studied XR welding trainer integration into welding instruction. The groups were divided into four modalities:100% XR training, 75% XR training, 25% traditional training, 50% XR and 50% traditional training, and 0% XR training. The study's results support that int XR welding trainers can positively impact training welding students. The treatment group that performed best in the weld performance was the group that trained with the XR welding trainers 75% of the time. An interesting finding of this study is that the 100% XR group outperformed all other groups in the 1G weld.

Byrd et al. (2018). Stone et al. (2013), Srinivas et al. (2020), and Wells and Miller (2020) suggest that there may be merit to the integration of XR technology into welding instruction. However, there needs to be more conclusive research on the optimal methodology based on the experience level of the welding student, the weld complexity, the instructional sequencing of simulators into instruction, and instructional time. Rose et al. (2015) researched the sequence of practicums in an agriculture program. The welding sequence contained four different modalities of integrating XR welding simulators and did not identify significant differences in learner outcomes (Rose et al., 2015). The Australian military research indicated a few findings, including evidence suggesting that combining virtual and formal training was the most effective method.

Further Research Opportunities

Based on the literature review, there is a need for additional research on the optimal use of XR simulator welding training tools in welding instruction. Present findings suggest that novice welding students can benefit from XR welding simulators. However, a transparent model must be developed to integrate XR welding trainers into instructional courses. Furthermore, there is little research on advanced welding methodologies and XR training. While research suggests that XR welding trainers have some efficacy with entry-level welding students, there is little supporting evidence for welds involving tungsten gas or flux cores.

Chapter III: Methodology

This chapter describes the research design and methodology used in this study. The research questions and hypotheses that guided the research are provided. Additionally, this chapter details the quasi-experimental design and the data collection and analysis methods.

Research Design

This study used a quasi-experimental design to compare the outcomes of different treatment groups. The study's goal was to evaluate the performance outcomes of participant groupings based on whether XR technology training was used in the curriculum. Moreover, the study also evaluated the sequencing of XR simulators into the instruction cycle. According to Shadish et al. (2001), quasi-experimental designs are used to analyze the results of interventions in treatment groups and do not have an explicit randomness requirement. Therefore, this design was chosen for this study to accommodate the challenge of implementing a fully random sampling process. In this study, participants chose to participate in the college's workforce welding program for beginning welders. Furthermore, the feasibility and ethical considerations of random assignment to a workforce welding program were impractical in this educational setting that served pre-employment students who were training in part for the immediacy of employment. Still, the research design minimized challenges to validity by controlling for prior exposure to welding of the participants. Also, instructor qualifications required that the instructor had a minimum of three years of experience as a welding instructor and was employed at the institution for at least two full semesters.

For this study, the welding instructor collected data from students who had provided informed consent. To evaluate the effect of the sequence of welding practice with extended reality (XR) training equipment on student performance required the instructor to provide three different instructional strategies to three welding cohorts.

Purpose of the Study

The focus of this study was to investigate the efficacy of integrating XR simulators into traditional welding training programs. Specifically, this analysis evaluated the technical skill attainment of welding students and their performance outcomes on live welds. Furthermore, the researcher assessed the results of implementing XR technology practice during the welding instruction cycle. During the COVID-19 pandemic, the need to deliver remote instruction was necessary. Because welding is equipment and resource intensive and requires safety protocols, traditional welding training was not feasible or reasonable. Consequently, the southern regional college and workforce partners explored alternative training opportunities and methodologies.

The college invested in XR welding simulators as training tools to continue workforce training during the pandemic. To support the integration of XR technology in the workforce, there needed to be more body of evidence to develop best practices. Therefore, this study aimed to contribute to this knowledge base. Therefore, this study focused on performance outcomes related to XR welding simulators as training tools and the sequencing of XR welding simulators into the curriculum.

Research Questions

The primary research question was, “Does the sequencing of welding practice with extended reality (XR) training equipment affect student welding performance as measured by the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position assessment?”. The following research questions were used to illuminate the primary question.

Research Question 1. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice in addition to traditional welding instruction?

H_0: $\mu_T = \mu_{XRC}$

H_A: $\mu_T > \mu_{XRC}$

Research Question 2. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction?

H_0: $\mu_T = \mu_{XRB}$

H_A: $\mu_T > \mu_{XRB}$

Research Question 3. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_T = \mu_{XRF}$

H_A: $\mu_T > \mu_{XRF}$

Research Question 4. Do welding students who receive XR practice before traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

$H_0: \mu_{XRB} = \mu_{XRF}$

$H_A: \mu_{XRB} > \mu_{XRF}$

Description of the Population

The population of interest was welding students enrolled in a welding technology program in the workforce division of a southern regional college. The population comprised of students who self-selected to enroll in a workforce training program to attain welding skill proficiency. These students were within commuting distance from the designated welding training site.

The population was limited to persons ages 18 years old or older who voluntarily signed up for welding workforce training. The population did not have a prior work history in welding. The population attended onsite training. All persons in this population completed welding safety training.

Participant Selection

The population of interest was entry-level welding students enrolled in a welding technology program at the southern regional college. Participants were enrolled in a welding class as part of a career-technical workforce program. The participants entered the program voluntarily and completed basic safety training. The researcher provided the students in the program with an informed consent document that explained the purpose of the study and notified the user that participation was voluntary and that there was no academic penalty associated with choosing not to participate.

Once informed consent was provided, the participant sample was finalized. A sample of such students was randomly assigned to one of three treatment groups. Treatment Group A was labeled the green schedule and received 20 hours of welding instruction with labs on live traditional welding equipment only. Treatment Group B was labeled the blue schedule and received welding instruction with the first 10 lab hours on live traditional welding equipment followed by 10 lab hours on Miller's AugmentedArc welding trainer. Treatment Group C was labeled the red group and received welding instruction with the first 10 lab hours on Miller's AugmentedArc welding trainer, followed by 10 lab hours on live traditional welding equipment.

Risks

The risks associated with this study were limited. The participants chose to enroll in a welding program. The program attendance was voluntary and had an open entry and open exit policy. The participant received basic safety training as a prequalifying condition to participate in the study and the class. The risks related to the welding instruction were such that the student already assumed the risks with their voluntary enrollment in the workforce welding training program.

One possibility was that the study design could mitigate risks for treatment groups that used the virtual welding technology. This was because virtual technology inherently reduces the risk of burn injury since it does not contain the live arc of traditional welding equipment. While the study was unlikely to impact the risks the welding students assumed, the students may have experienced concern or stress from the assignment of treatment groups. Additional risks may have included increased pressure or concern about their welding submissions being rated by the independent Certified Welding Instructor.

Instrument

This study used a performance-based assessment provided by NCCER. The performance assessment was a standard assessment in the certification process for qualifying entry-level skilled professionals. The performance assessment was designed to assess the weld type and specifications of the weld type taught during the initial 20 hours. The assessment instrument was selected because of the welding industry's broad acceptance of it. Also, it was an assessment regularly used in the program to rate performance outcomes. The instrument was used frequently by the CWI. Furthermore, the instrument was specifically for the vertical 3F weld, which corresponded to the performance assessment for this study. Additionally, the performance assessment was designed for use with the specific weld technique used in this study, which was SMAW.

The instrument listed the performance criteria by both weld type and position. For each participant, the graded acceptance checklist was provided. The checklist indicated the performance acceptance and quality of the performance. Each treatment group used the same checklist, except the treatment color was noted on the assessment form. The student's name and other personally identifiable information were not added to the form. However, the instructor reviewed all assessment forms for personally identifiable information as a secondary measure. Any personally identifiable information that would jeopardize the anonymity and privacy of the participant was scrubbed before being provided to the researcher. Only the participant's first weld attempt for the assessment was accepted. Participants were not allowed to make a second attempt or additional corrective measures to the weld coupon post-assessment.

Data Collection and Security

Institutional Review Board

The Murray State University (MSU) Institutional Review Board (IRB) granted permission to proceed with this study on October 24, 2022. The IRB identifier assigned by the MSU IRB was IRB #23-069. In accordance with the IRB, the researcher followed the requirements of the approved parameters of the study for MSU and the approved guidelines provided by the southern regional college that provided the welding site.

Informed Consent

Before beginning the study, the researcher provided each potential participant with two hard copies of the informed consent document. One copy was to be signed, and the second was to be retained by the participant. The informed consent document contained an explanation of the nature of the study, a statement that participation was voluntary, and a statement indicating that there was no penalty associated with choosing not to participate. The informed consent document stated that the participant could exit the study at any point. The document was signed and dated by participants indicating their agreement to release the result of their welding assessment.

Security

The informed consent documents were secured in a locked drawer and will be retained for three years and then shredded. No identifying information on the data set was provided. Only the research team had access to review the raw data. The data are archived on the primary researcher's MSU cloud account provided through Google with AES algorithm encryption for data at rest and TLS encryption for data in transport to the internal emails of the research committee. Digital data will be digitally sanitized, at which time it is acceptable.

Data Collection

After 20 lab hours, the participants in all treatment groups performed the same weld on a steel weld coupon. The weld was the vertical 3F using SMAW. The work samples were analyzed by an independent certified welding instructor (CWI) using a performance-based assessment instrument to grade the quality of welds. The NCCER performance assessment tested eleven different criteria. The performance assessment ratings were correlated to a numerical scale developed through the study's pre-research stage. The assessment score for each student was recorded, and the mean score was calculated for each of the three treatment groups. The CWI provided the performance assessments to the researcher. Any data that had identifiable information remained in the instructor's possession and was handled following the host college's policy.

Once the data were reviewed and cleared for transmittal to the researcher, the data were collected. No personally identifiable grades were provided to the researcher. The data sets were aggregated, and a mean was calculated. The relationship between the method of instruction and the mean score on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position was analyzed using a series of t-tests. The data were maintained on the researcher's password-protected computer and contained no personally identifiable information.

Variables

The independent variable was labeled "instruction method," a categorical variable with three different options for this study. The three instruction method options were:

- Treatment Group A used the green schedule and received welding instruction with only 20 hours of labs on live welding equipment.
- Treatment Group B used the blue schedule and received welding instruction with the first 10 lab hours on live welding equipment, followed by 10 lab hours on Miller's Augmented Arc welding trainer.
- Treatment Group C used the red schedule and received welding instruction with the first 10 lab hours on Miller's Augmented Arc welding trainer, followed by 10 lab hours on live welding equipment.

The dependent variable was the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position score. The NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position score was a quantitative variable. The raw data set was limited to the number of qualified participants enrolled in the workforce training program. For analysis purposes, categorical variables were labeled. For the variable “method of instruction,” 1= “traditional,” 2 = “live weld before XR weld,” and 3 = “live weld after XR weld.”

Data Analysis

The t-test was used to evaluate the sample means for statistically significant differences. The t-test was an appropriate test for assessing these samples. According to Ravid (2020), the t-test was suitable for the study because it evaluated the difference between the quantitative variables from the two groups. The t-test was used to compare the two data sets that were numerically averaged and assessed for a statistically significant difference (Ravid, 2020).

In the data analysis, the researcher performed a series of four t-tests. The t-test was used because it was an acceptable statistical analysis method to establish evidence that the means of two populations are not the same. Furthermore, the data met the conditions outlined by Ravid (2020) for samples that are independent of each other. Each treatment group had a corresponding data set of raw scores on a performance weld that the CWI scored. Each treatment data set was independent of the other treatment data sets. Each data set of participants' scores who received a specific treatment in the study was aggregated and evaluated for a numerical mean. This numerical mean was used in the t-test evaluation.

The t-test for independent samples was an acceptable test, according to Ravid (2020), because the two sets of scores were independent, and the means served as the comparing data point. Additionally, the data sets were appropriate for calculating a numerical mean for this test because the mean was calculated from the sample's raw test score based on interval data, which were an acceptable data type for the t-test on independent samples (Ravid, 2020).

Chapter IV: Findings and Analysis

This study investigated the efficacy of integrating XR welding simulators into traditional training programs. Specifically, the focus of this study was to evaluate the technical skill attainment of welding students and their performance outcomes on both live welds and XR welding simulators in the instructional cycle.

Research Questions

The primary research question was, "Does the sequencing of welding practice with extended reality (XR) training equipment affect student welding performance as measured by the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position weld assessment?". The following research questions were used to illuminate the primary question.

Research Question 1. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice in addition to traditional welding instruction?

H_0: $\mu_T = \mu_{XRC}$

H_A: $\mu_T > \mu_{XRC}$

Research Question 2. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction?

H_0: $\mu_T = \mu_{XRB}$

H_A: $\mu_T > \mu_{XRB}$

Research Question 3. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_T = \mu_{XRF}$

H_A: $\mu_T > \mu_{XRF}$

Research Question 4. Do welding students who receive XR practice before traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_{XRB} = \mu_{XRF}$

H_A: $\mu_{XRB} > \mu_{XRF}$

Sample

The participants were students in a workforce non-credit training program. Each person self-selected to enroll in the training program. The participants were at least 18 years old. The sample population had no prior welding experience and voluntarily enrolled in a non-credit, tuition-free workforce welding program. All participants completed the safety component of the program before beginning the welding instructional cycle.

The participants were enrolled in the first rotation of the spring semester of a non-credit welding program at the large southern regional college. Three primary factors limited the size of the sample. The first factor was the availability of welding workstations and virtual welding stations. The second factor was the number of recruits available to participate in the non-credit welding program at the beginning of the academic term in January 2023. The third factor was informed consent. All participants were given the option to participate and release their data. There were 15 participants that met the conditions and provided informed consent. All participants completed the study and provided weld coupon samples for evaluation.

All participants trained with Miller Weld's equipment. The XR training was conducted on a Miller Augmented Arc extended reality welding system, and the traditional live welding was on a Miller live welding machine. Instruction was provided by a welding instructor with greater than three years of experience training welding students and prior experience using virtual welding simulations in education. Participants were randomly assigned to one of three treatment groups to evaluate the effect of the sequence of welding practice with extended reality (XR) training equipment on student performance.

In this workforce training program, the practice was to begin entry-level welding students with shielded metal arc welding (SMAW). To control for weld techniques, SMAW welding was used exclusively for the duration of the study. Additionally, all treatment groups instructed the participants to perform a 3F weld vertically using SMAW. Each participant received only one of the three instructional strategies based on their treatment group placement. Treatment Group A received 20 hours of instruction with labs on the Miller live welding equipment exclusively. Treatment Group B’s first 10 lab hours used Miller live welding equipment for 10 hours, followed by 10 lab hours on a Miller Augmented Arc extended reality welding trainer. Treatment Group C’s welding instruction began with the first 10 lab hours on a Miller Augmented Arc extended reality welding trainer, followed by 10 lab hours on Miller live welding equipment.

Data Collection

After participants in the treatment groups reached 20 lab hours, they performed the 3F vertical weld using SMAW welding on a traditional Miller live welding machine. The work samples were steel weld coupons and were assigned a four-digit code known to the instructor only. A certified welding instructor (CWI) collected and analyzed the weld coupons. The CWI used a standard assessment for all work samples. The performance assessment tool from the NCCER program evaluated each work sample based on the standardized criteria for the 3F SMAW weld. A copy of the evaluation was provided to the researcher.

Procedures for Data Analysis

The sample was limited to an initial spring term 2023 cohort. Each treatment group had five participants. The dataset was analyzed using a t-test to evaluate the sample means for statistically significant differences. The t-test was used because of its functionality to compare two data sets that are numerically averaged and assessed for a statistically significant difference (Ravid, 2020). Each treatment group had a corresponding data set of raw scores on 3F SMAW vertical welds scored by a certified welding instructor (CWI) using the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position.

Participant scores were aggregated by their treatment group and evaluated for a numerical mean. This numerical mean was used in the t-test evaluation. Each treatment group's mean raw score and standard deviation were calculated and are displayed in Table 1.

Table 1

Summary Statistics by Treatment Group

Treatment Group	Number	Mean Raw Score	Standard Deviation
Traditional Welding Only	5	102.4	4.4
XR Practice before Traditional Welding	5	87.6	24.2
XR Practice after Traditional Welding	5	63.4	15.7
XR Combined Group	10	75.5	23.0

Findings

Traditional Welding Compared to XR Welding

Research Question 1: Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice in addition to traditional welding instruction?

H_0: $\mu_T = \mu_{XRC}$

H_A: $\mu_T > \mu_{XRC}$

The Research Question 1 claim was evaluated using a two-sample t-test to determine if the mean raw score of the traditional-only group was greater than the mean raw score of the XR combined group.

T statistic = 3.56

p value = 0.0025

The results of the t-test indicate that the treatment group of entry-level welding students who received training exclusively using traditional, live welding equipment had a higher mean raw score on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position (*M* = 102.4, *SD* = 4.4) than did those training with extended reality welding simulators in addition to traditional training with live welding equipment (*M* = 75.5, *SD* = 23), t(10) =3.56, *p* = .0025.

Due to the low p value of .0025, the null hypothesis was rejected. There was sufficient evidence to support the claim that welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who received XR practice in addition to traditional welding instruction (see Appendix A).

Traditional Welding Compared to XR Before Traditional Welding

Research Question 2. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction?

H_0: $\mu_T = \mu_{XRB}$

H_A: $\mu_T > \mu_{XRB}$

The Research Question 2 claim was evaluated using a two-sample t-test to determine if the mean raw score of the traditional-only group was greater than the mean raw score of the XR before the traditional welding instruction group.

T statistic = 1.35

p value = 0.1224

The results of the t-test indicated that the treatment group of entry-level welding students who received training exclusively using traditional training with live welding equipment had a higher mean raw score on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position (*M* = 102.4, *SD* = 4.4) than did those training with extended reality welding simulators before receiving traditional welding training with live welding equipment (*M* = 87.6, *SD* = 24.2), t(10) =1.35, *p* =.1224.

The result of the t-test was a p value greater than .05 (p = .1224). Therefore, the researcher failed to reject the null hypothesis. There was not sufficient evidence to support the claim that welding students who received only traditional welding instruction performed better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who received XR practice before traditional welding instruction (see Appendix B).

Traditional Welding Compared to XR After Traditional Welding

Research Question 3. Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_T = \mu_{XRF}$

H_A: $\mu_T > \mu_{XRF}$

The Research Question 3 claim was evaluated using a two-sample t-test to determine if the mean raw score of the traditional-only group was greater than the mean raw score of the XR practice following traditional welding instruction.

T statistic = 5.35

p value = 0.0019

The results of the t-test indicated that the treatment group of entry-level welding students who received training exclusively using traditional training with live welding equipment had a higher mean raw score on the NCCER SMAW Performance Accreditation Task Filet Weld with

E7018 Electrodes in the Vertical (3F) Position (*M* = 102.4, *SD* = 4.4) than did those who trained with extended reality welding simulators after receiving traditional welding training with traditional, live welding equipment (*M* = 63.4, *SD* = 15.7), t(4.62) =5.35, *p* = .0019.

The null hypothesis was rejected due to a p value less than .05. There was sufficient evidence to support the claim that welding students who received only traditional welding instruction performed better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who received XR practice following traditional welding instruction (see Appendix C).

XR Before Traditional Welding Compared to XR After Traditional Welding

Research Question 4. Do welding students who receive XR practice before traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?

H_0: $\mu_{XRB} = \mu_{XRF}$

H_A: $\mu_{XRB} > \mu_{XRF}$

The Research Question 4 claim was evaluated using a two-sample t-test to determine if the mean raw score of the XR practice before the traditional welding group was greater than the mean raw score of the XR practice following traditional welding instruction.

T statistic = 1.88

p value = 0.0516

The researcher failed to reject the null hypothesis due to a p value greater than .05. There was not sufficient evidence to support the claim that welding students who receive XR practice before traditional welding instruction performed better on the NCCER SMAW Performance

Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who received XR practice following traditional welding instruction (see Appendix D).

Summary

The focus of this study was to investigate the value of integrating XR welding simulators into traditional training programs. The study specifically examined the performance outcomes of entry-level welding students in a non-credit training program after their first 20 hours of lab instruction. The study's findings indicated that the sequence of the XR welding simulators into welding instruction yielded different performance outcomes.

Evaluation of the raw mean scores using t-test analysis indicated no significant difference in the mean scores of the treatment group that had XR training before the traditional welding group and the treatment group that had only traditional, live welding. Conversely, there was significant evidence that traditional welding on live welding equipment outperformed training with an XR trainer when the XR trainer was used following welding practice on a live trainer. The traditional welding equipment-only group also outperformed the combined XR welding group.

Chapter V: Conclusions and Discussion

The findings of this research were derived from a quasi-experimental study in the spring semester of 2023 at a southern regional community college. The study evaluated the efficacy of extended reality (XR) simulators in welding training programs. The performance outcomes of participants were assessed by an independent American Welding Society (AWS) Certified Welding Instructor (CWI).

Study Summary

A southern regional community college's entry-level workforce training program purchased XR welding trainers during the COVID-19 pandemic. As the pandemic ended, the community college wanted to understand how to optimize the implementation of XR welding simulators into future training programs. Furthermore, the college sought to determine whether they should continue to invest in XR welding simulators. To address these questions, the welding quality of vertical 3F welds was evaluated. Participants randomly assigned to one of three treatment groups performed a vertical 3F weld using Shielded Metal Arc Welding (SMAW). The three treatment groups were:

- Traditional welding instruction for 20 hours and no exposure to XR welding
- XR welding practice for ten hours, followed by ten hours of traditional welding instruction.
- Traditional welding instruction for ten hours, followed by ten hours of XR welding practice.

The CWI used the Vertical 3F SMAW NCCER performance assessment for each treatment group. Each treatment group's raw data were compiled, a mean was calculated, and a series of t-tests were performed.

The first research question was, “Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice in addition to traditional welding instruction?”. The results indicate that welding students who receive only traditional welding instruction perform better than those who receive XR practice in addition to traditional welding instruction (see Appendix A).

The second research question was, “Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction?”. The results do not support the claim that welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice before traditional welding instruction. The research findings indicate no statistically significant difference between the means of the two groups (see Appendix B).

However, there was a significant difference in the means of the groups analyzed in the third research question, “Do welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?”. There was sufficient evidence to support the claim that welding students who receive only traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F)

Position than those students who received XR practice following traditional welding instruction (see Appendix C).

Finally, the fourth research question was, “Do welding students who receive XR practice before traditional welding instruction perform better on the NCCER SMAW Performance Accreditation Task Filet Weld with E7018 Electrodes in the Vertical (3F) Position than those students who receive XR practice following traditional welding instruction?”. When evaluated at a significance level of .05, the findings are not statistically significant due to a p value of .052 (see Appendix D), which means there is a 5.2% probability that the results are due to randomness and a 94.8% likelihood that there is an explanatory factor involved such as the method of welding instruction given to the treatment group. While the researcher set a 5% significance level as the threshold for statistical significance, noting this small likelihood of random chance is important. In fact, if the researcher had set a significance level of 6% as the threshold for statistical significance prior to the study, then the finding would be considered statistically significant. While the most often used significance level is 5%, 1% and 10% are also used regularly (Triola, 2022).

Conclusions

The primary research question was, “Does the sequencing of welding practice with extended reality (XR) training equipment affect student welding performance as measured by the NCCER weld assessment?”. The findings indicate that including XR practice before traditional welding instruction did not affect student performance on the NCCER weld assessment. Additionally, statistically significant results were that traditional welding instruction yields better performance outcomes than using XR welding simulators when the sequence of XR welding simulators in the training program is not considered.

Also, evidence suggests that XR practice before traditional welding instruction has merit. The findings are not statistically significant at a 5% threshold. However, a p value of .052 does have merit that XR practice before traditional welding instruction yields a positive performance outcome compared to XR practice after traditional welding instruction.

Finally, the data did not support that XR practice after traditional welding instruction led to better performance outcomes than traditional welding instruction only. With a p value of $p < .001$, the evidence supports the claim that traditional welding instruction yields performance outcomes greater than or equal to those outcomes from XR practice after traditional welding instruction. (see Appendix D).

The body of evidence in this study indicates that using XR welding simulation technology before traditional welding equipment in welding instruction does not have a significantly different outcome than using only traditional welding instruction. The value of this finding is that there is no significant evidence that XR welding simulation technology before traditional training is detrimental to the learning outcomes of welding students' performance compared to the performance of students who received only traditional welding instruction.

Wells and Miller (2020) recommended that the sequencing of XR welding technology into the instructional cycle be explicitly evaluated for entry-level welding students because their study did not control the welding student's skill level. The present study followed Wells and Miller’s (2020) recommendation, including only entry-level welding trainees. The present study’s findings did not concur with Wells and Miller’s (2020) conclusion that there was no statistical evidence to support XR simulators in welding workforce training. The current research indicates that if XR technology is integrated into welding, the sequence of the integration of XR welding simulator technology should be XR first, followed by traditional welding. This integration does not significantly differ from traditional, live welding training only. XR after traditional welding does have a significant negative impact on performance outcomes. Therefore, the recommendation is to integrate XR technology at the beginning of the instructional cycle and transition to traditional welding equipment.

The present study's findings affirm Whitney and Stephens (2014) and Byrd et al. (2015) that there is a benefit to using virtual welding simulators for entry-level welding skill attainment. This study's findings support Whitney and Stephens (2014), who reported evidence suggesting that integrating virtual welding simulators into traditional welding training could assist novice welding students by instructing them with XR welding practice before traditional welding.

Wells and Miller's (2020) findings at Iowa State University found that the performance outcome with the poorest results was the treatment group with the first 50% of their training with XR technology, followed by 50% training with traditional welding instruction. The current study's findings differ from Wells and Miller (2020). The present study finds no statistical difference in performance outcome by the 50% XR followed by the 50% traditional welding instruction. Additionally, the current research findings indicate that traditional welding outperforms XR training when the sequencing of XR integration is not considered.

Wells and Miller (2020) did not control for purpose or motivation in their study. They assessed learners with various college majors. Wells and Miller (2020) conducted their assessment after training the participants for one hour. In contrast to Wells and Miller (2020), this present study evaluated performance outcomes after 20 hours and used only entry-level welding students training for workforce entry. The study by Wells and Miller (2020) did not have statistically significant findings but did report that the 100% XR welding practice yielded the best outcome, the traditional-only practice group produced the second-highest performance outcome, and the 50% XR to the traditional group had the lowest performance outcomes. Wells and Miller (2020) and this present study used an AWS CWI to evaluate performance outcomes. Possible explanations for the differing results of this study from Wells and Miller (2020) is that the present study assessed participants at 20 hours, and the participants were training for employment.

Stone et al. (2013) strengthen the argument that time on the XR welding simulators may impact performance outcomes. Stone et al. (2013) indicated that although the treatment group was 50% virtual and 50% traditional, it outperformed the control group and had more practice time than the 100% traditional welding control group. Stone (2013) did not limit or standardize the practice time of the groups.

The findings of XR sequencing before live welding compared to sequencing XR after live welding instruction had significantly different performance outcomes. The XR before did not have a statistically significant difference from the live welding-only group. However, the XR after live welding was detrimental to the performance outcomes assessed on the NCCER performance accrediting task checklist.

One potential explanation for the difference between the two XR groups is rooted in connectivism, which views the learner as one of the components of the welding instructional system (Siemens, 2005). The blurring of agency between person and machine in XR technology creates a user-centered, experiential learning system. Using connectivism as the theoretical foundation is useful for providing insight into why learners in the XR before live welding group had a better performance outcome than the XR after the live welding group. Connectivism indicates that the initial exposure to welding through immersion in the XR system was unencumbered with safety concerns and material consumption costs due to errors. Additionally, the low-cost, low-risk integration of XR early in the instructional cycle allowed the learner to use trial and error and experience what-if scenarios without consequences. For example, a typical learning curve with SMAW often has the learner sticking the rod, which leads to an unusable rod and a damaged weld surface.

Furthermore, Blom and Bechhaus's (2013) Dynamic Interactive Virtual Environments (DIVE) taxonomy demonstrates how this experiential practice first in the XR environment benefitted the learning process by providing sensory feedback and ongoing positive engagement with the system. While both XR before and XR after received 10 hours on the XR simulators, the initial experiential learning and the lower risk during the XR first group allowed for inquiry and confidence building. The XR after live welding group did receive sensory feedback, but it may have been only one part of the learning experience. For example, the XR last group would have experienced a live welder on their first day. During these initial ten lab hours on the live welding equipment, the trainees must divide their attentiveness between safety precautions, live arc, high temperatures, and weld pools.

Another possible explanation is that the XR after the live welding group may have devalued the XR immersive experience as a step back instead of a step forward in the learning process. In this scenario, the connectivist perspective would indicate that a devaluing of the skill development potential of the XR system would occur (Siemens, 2005). This absence of perceived practicality is also supported by Steffen et al. (2019)'s XR affordances instruction framework which asserts that user acceptance of the XR instruction is higher with utility. Finally, Price et al. (2019)'s study indicated that as a student gains experience with the live welder, they are less like to embrace the XR welder because the difference between the traditional and XR welders are such that XR falls short of an authentic experience.

Practical Significance

Providing information to instructional leaders regarding performance outcomes offers insight that can influence educational practices and purchasing decisions. There is no significant difference between live welding-only instruction and using XR simulations before traditional live welders provide financial advantages in training, supplies, and equipment (Chan et al., 2022).

Chan et al. (2022) determined that supply chains, materials, and skilled workers are in short supply. The findings of this study on XR welding simulations enable decision-makers to exercise data-informed decisions that can aid in optimizing the procurement of appropriate equipment during a supply chain disruption or an economic downturn. The findings of this research have the potential impact of reducing up to 50% of the costs of training materials by offering an andragogical methodology for integrating XR technology into welder education due to the findings of no statistical significance in the performance outcomes of XR before traditional welding using 50% of the time on XR simulators and 50% of the time on traditional welders, with the sequencing being XR training before traditional welding training.

Additionally, this study provides data regarding instruction using XR technology in welding training programs. This study's findings provide valuable information for the strategic implementation of XR training protocols when implementing XR welding simulations. Specifically, sequencing XR simulations before traditional, live welding training in entry-level programs does not have a significant performance outcome difference from traditional welding. This finding supports the implementation as a low-risk decision that can alleviate supply chain challenges with purchasing, supplying, and covering material training costs (Chan et al., 2022).

Also, knowledge of XR training strategies provided the college's workforce partners with information that could empower them to adapt their training practices.

Furthermore, because this study's findings show that integrating XR technology into welding training after introducing traditional welding equipment leads to adverse performance outcomes compared to the traditional welding-only group, the recommendation is that XR welding simulations should not be used after the introduction of traditional welding. The awareness of this cautionary finding allows instruction and curriculum to focus on other potential solutions.

P-20 Implications

Piotrowski and King (2020) and Trust et al. (2020) found that using traditional welding teaching strategies was unsuccessful and called for innovation to support remote learning in welding education. This study provides foundational research to support best practices using XR welding simulations in welding education. Additionally, the findings extend to workforce training and can provide supporting evidence for focusing on sequencing strategies when including XR simulators.

Also, the study findings provide P-20 innovators with supporting evidence that sequencing is crucial to XR integration and should be considered in future workforce education and disaster mitigation approaches. In present instructional models, many training entities have invested in XR welding simulators. However, a standard on the best way to use these tools must be established. This study offers a framework for sequencing instruction with XR technology in welding training programs. Of specific interest to P-20 leaders is that the findings support that training programs that integrate XR simulators should sequence XR welding practice before traditional welding instruction.

Furthermore, the results offer guidance on integrating XR welding simulators into training to optimize learner advancement in teaching models that incorporate elements of remote education by informing instructional leaders to think strategically about the timing and sequencing of virtual labs using XR technology and live traditional welding. Also, the study findings support that teaching XR technology integration can reduce material costs and improve the return on investment. The economic recovery could support further growth and opportunities.

The study’s findings empower instructional leaders to make informed decisions. Also, the results challenge inaccurate preconceptions about integrating XR welding simulators into welding training. The findings also affirm the value of traditional welding instruction. The study findings indicate that XR welding does not replace traditional welding instruction. The results do not support replacing traditional live welding equipment with virtual welding equipment. Specifically, the findings indicate a significant difference in outcomes of the combined XR treatment groups compared to the traditional-only group. However, instruction outcomes in this study for the XR before the traditional group and the traditional group did not have significant differences. Leaders can benefit from the evidence to support when XR instruction is acceptable to integrate into the instruction based upon when traditional welding equipment is used in the instructional cycle.

Finally, there are implications for the classroom. Skills attainment is a primary goal of workforce welding training. This study illuminates the opportunities and limitations of XR welding simulation integration in the instructional cycle, potentially influencing the learner's engagement with the instructor if XR technology is used without instructor presence. In a formal welding training program, the instructional team can build upon the results to develop best practices for remediation and practice with XR welding simulators. The instructor can adapt instructional strategies by understanding the challenges of integrating XR technologies.

Limitations of the Study

Participants

This study used a limited number of participants due to the availability of eligible applicants at the time of the study. The sample population was limited to persons who were at least 18 years old, had no prior welding experience, and desired to participate in a workforce training program requiring 20 hours per week of in-person training for 15 weeks. Additional challenges with participant numbers were the limitation of available welding booths and equipment.

Weld Technique and Type

This study focused specifically on the SMAW technique and examined the sequencing of the integration of XR welding technology into the instructional cycle in a workforce welding training program. The data collection was a single weld type, the vertical 3F weld taken after 20 hours of instruction and evaluated by a CWI. The results of this study are not inclusive of multiple weld types. Using SMAW welding and assessing vertical 3F welds at 20 hours of training is not a uniform instructional strategy. Therefore, the findings are not necessarily generalizable to other welding techniques or types.

Instructional Program

The focus of the research design involved a highly regimented instructional program for the first 20 hours of the workforce development program offered through a southern regional community college as part of a non-credit learn-to-earn model. Because the instructional program aimed to provide immediate employment based on mastery components, it was both an open entry and open exit program. Entry into the class was provided when space was available. Space for enrollment became available when one of the following exit conditions occurred:

- A student left the program without completion.
- A student met the mastery benchmarks before 15 weeks.
- A student left the program early due to an offer of welding employment.

Instructional Format

The target population participated in a training schedule of 20 hours per week for a maximum of 300 hours over 15 weeks. The program design and purpose led to a narrow focus on a niche group who needed to gain welding experience, desired welding workforce training, met the enrollment criteria, and could attend a non-credit program with structured instructional times. The participants in this study had to be at least 18 years old and self-selected to enter a workforce training program.

Welding Technology

Technological advances in XR welding simulation equipment, software enhancements, and enhanced multisensory experiential learning are anticipated. Therefore, the research findings are limited to the technology available for the study. This study used Miller welding equipment for traditional and XR training experiences. The Miller Augmented Arc was used to deliver the XR welding simulator training.

Recommendations for Future Research

The researcher recommends that future studies investigate different time intervals of XR welding simulators in welding training before integrating traditional, live welding training. Another recommendation is to conduct a longitudinal study to evaluate XR welding simulators' long-term impact on the instructional cycle for career welding professionals. Future researchers should also consider approaches that assess participants' performance over time or through assessments, certifications, and course completion outcomes.

Furthermore, more research is needed to evaluate different combinations of trainers, weld types, and weld techniques. Further research should consider the present welding technology and replace the XR welding simulator used in this study with state-of-the-art welding trainers as they come to market. Additionally, further research is needed to evaluate the impact of time, motivation, and practice based on the findings of Wells and Miller (2020), Stone et al. (2013), Byrd et al. (2015), and this study.

References

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General*, *117*(3), 288–318. https://doi.org/10.1037/0096-3445.117.3.288

Acosta, J. L., Navarro, S. M., Gesa, R. F., & Kinshuk, K. (2019). Framework for designing motivational augmented reality applications in vocational education and training. *Australasian Journal of Educational Technology*, *35*(3). https://doi.org/10.14742/ajet.4182

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior*, *3*(2), 111–150. https://doi.org/10.1080/00222895.1971.10734898

Aguinas, H., Henle, C. A., & Beaty Jr., J. C. (2001). Virtual reality technology: A new tool for personnel selection. *International Journal of Selection and Assessment*, *9*(1&2), 70–83. https://doi.org/10.1111/1468-2389.00164

American Welding Society. (1976). *Welding handbook: Fundamentals of welding* (7th ed.). Macmillan Education. https://doi.org/10.1007/978-1-349-03073-6

Baxter, J., & Hepplewhite, R. (1999). Agents in tank battle simulations. *Communications of the ACM*, *42*(3), 74–75. https://doi.org/10.1145/295685.295860

Benokraitis, N. V. (2011). Marriages & families: Changes, choices, and constraints - census update (7th ed.). Pearson.

Blom, K. J., & Beckhaus, S. (2013). The design space of dynamic interactive virtual environments. *Virtual Reality*, *18*(2), 101–116. https://doi.org/10.1007/s10055-013-0232-y

Bowman, D. A., & Hodges, L. F. (1999). Formalizing the design, evaluation, and application of interaction techniques for immersive virtual environments. *Journal of Visual Languages & Computing*, *10*(1), 37–53. https://doi.org/10.1006/jvlc.1998.0111

Braverman, H. (1974). *Labor and monopoly capital*. Monthly Review Press.

Brunnström, K., Dima, E., Qureshi, T., Johanson, M., Andersson, M., & Sjöström, M. (2020). Latency impact on quality of experience in a virtual reality simulator for remote control of machines. *Signal Processing: Image Communication*, *89*, 1-19. https://doi.org/10.1016/j.image.2020.116005

Byrd, A. P. (2014). *Identifying the effects of human factors and training methods on a weld training program* [Doctoral dissertation, University of Iowa]. Iowa State University Digital Archive. https://dr.lib.iastate.edu/entities/publication/d6cc9f8f-c90a-4ab6-9df8-3d5f536fbfe3

Byrd, A. P., Stone, R. T., & Anderson, R. G. (2018). Dexterity: An indicator of future performance in beginning welders. *Career and Technical Education Research*, *43*(2), 195–212. https://doi.org/10.5328/cter43.2.195

Byrd, A. P., Stone, R. T., Anderson, R. G., & Woltjer, K. (2015). The use of virtual welding simulators to evaluate experienced welders. *Welding Journal*, 389–395.

Caruth, D. L., & Caruth, G. D. (2018). Managing workplace resistance to change. *Industrial Management*, *60*(4), 21-23.

CERN. (n.d.). *A short history of the web*. Retrieved June 18, 2022, from https://home.cern/science/computing/birth-web/short-history-web

Chan, V., Haron, H., Isham, M., & Mohamed, F. (2022). VR and AR virtual welding for psychomotor skills: A systematic review. *Multimedia Tools and Applications*, *81*(9), 12459–12493. https://doi.org/10.1007/s11042-022-12293-5

Chen, N., Ko, H., Kinshuk, & Lin, T. (2005). A model for synchronous learning using the internet. *Innovations in Education and Teaching International*, *42*(2), 181–194. https://doi.org/10.1080/14703290500062599

Chenarides, L., Manfredo, M., & Richards, T. J. (2020). Covid-19 and food supply chains. Applied Economic Perspectives and Policy, 43 (1), 270 - 279. https://doi.org/10.1002/aepp.13085

Committee on Developments in the Science of Learning. (2018). *How people learn II: Learners, contexts, and cultures (informal learning)* (Illustrated ed.). National Academies Press.

Dalgarno, B., & Lee, M. W. (2009). What are the learning affordances of 3-d virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Defense Advanced Research Projects Agency. (n.d.). *Paving the way to the modern internet*. DARPA. Retrieved June 18, 2022, from https://www.darpa.mil/about-us/timeline/arpanet

Dobrzański, L. A., Jagiello, A., & Honsysz, A. (2008). Virtual tensile test machine is an example of material science virtual laboratory post. *Journal of Achievements of Materials Manufacturing and Engineering*, *27*(2), 207–210. https://doi.org/10.1177/0306419019898824

Dong, H., Cong, M., Zhang, Y., Liu, Y., & Chen, H. (2018). Modeling and real-time prediction for complex welding process based on weld pool. *The International Journal of Advanced*

Manufacturing Technology, 96(5-8), 2495–2508. https://doi.org/10.1007/s00170-018-1685-7

Doshi, A., Smith, R. T., Thomas, B. H., & Bouras, C. (2016). Use of projector-based augmented reality to improve manual spot-welding precision and accuracy for automotive manufacturing. *The International Journal of Advanced Manufacturing Technology*, *89*(5-8), 1279–1293. https://doi.org/10.1007/s00170-016-9164-5

Erden, M. S., & Billard, A. (2016). Robotic assistance by impedance compensation for hand movements while manual welding. *IEEE Transactions on Cybernetics*, *46*(11), 2459–2472. https://doi.org/10.1109/tcyb.2015.2478656

Evans, S. (2007). Welding's Ivy League. *Tech Directions*.

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers & Education*, *127*, 252–266. https://doi.org/10.1016/j.compedu.2018.09.002

Ferris, K., & Stein, J. (2014). *The real world* (4th ed.). W. W. Norton & Company.

Fortune Insights. (2021). *Welding market size, share & COVID-19 impact analysis and regional forecast, 2021-2028* (Report ID FBI101657) [Market research report]. Fortune Business Insights. https://www.fortunebusinessinsights.com/industry-reports/welding-market-101657

Geser, H. (2006). Is the cell phone undermining the social order?: Understanding mobile technology from a sociological perspective. *Knowledge, Technology & Policy*, *19*(1), 8–18. https://doi.org/10.1007/s12130-006-1010-x

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development* (1st ed.). Oxford University Press.

Hawkes, R., Rushton, S., & Smyth, M. (1995). Update rates and fidelity in virtual environments. *Virtual Reality*, *1*(2), 99–108. https://doi.org/10.1007/bf02009726

Hillers, B., Aiteanu, D., & Gräser, A. (2013). Augmented reality helmet for the manual welding process. In *Virtual and augmented reality applications in manufacturing* (pp. 361–381). Springer London. https://doi.org/10.1007/978-1-4471-3873-0_18

Holzer, H. J. (2022, April 13). *Tight labor markets and wage growth in the current economy*. Brookings. https://www.brookings.edu/research/tight-labor-markets-and-wage-growth-in-the-current-economy/

Huang, C.-Y., Lou, S.-J., Cheng, Y.-M., & Chung, C.-C. (2020). Research on teaching a welding implementation course assisted by sustainable virtual reality technology. *Sustainability*, *12*(23), 10044. https://doi.org/10.3390/su122310044

Jeyaganesh, D., Ziout, A., & Qudeiri, J. A. (2021, May 13–15). *Optimization of P-GMAW parameters using Grey relational analysis and Taguchi method* [Paper presentation]. 2021 IEEE 12th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT), Cape Town, South Africa. https://doi.org/10.1109/ICMIMT52186.2021

Karstensen, S., & Lier, A. (2020). Virtual welding: A didactic perspective. *Nordic Journal of Vocational Education and Training*, 95–107. https://doi.org/10.3384/njvet.2242-458x.2010195

Keller, J. M. (2010). Five fundamental requirements for motivation and volition in technology-assisted distributed learning environments. *Revista Inter. Ação*, *35*(2). https://doi.org/10.5216/ia.v35i2.12668

Kobayashi, K., Ishigame, S., & Kato, H. (2001). Simulator of manual metal arc welding with the haptic display. *ICAT*.

Kramer, G. (1995). Sound and communication in virtual reality. In Biocca, F., & Levy, M.R. (Eds.) *Communication in the age of virtual reality* (pp. 262–279). Routledge. https://doi.org/10.4324/9781410603128-15

Lee, G. A. (2010). Virtual reality content-based training for spray painting tasks in the shipbuilding industry. *ETRI Journal*, *32*(5), 695–703. https://doi.org/10.4218/etrij.10.1510.0105

Lester, S., & Hofmann, J. (2020). Some pedagogical observations on using augmented reality in a vocational practicum. *British Journal of Educational Technology, 51*(3), 645–656. https://doi.org/10.1111/bjet.12901

Lincoln Electric. (n.d.). *Lincoln Electric education & welding training systems.* https://www.lincolnelectric.com/en/Education/Training-Programs/Education-Products/Welding-Training-Systems

Liu, Y. K., Shao, Z., & Zhang, Y. M. (2014). Learning human welder movement in pipe GTAW: A virtualized welding approach. *Welding Journal*, *93*, 388–398.

Miller Electric. (2022, April 13). *Addressing the welder shortage with advancements in technology*. Miller Welds. Retrieved June 17, 2022, from https://www.millerwelds.com/resources/article-library/addressing-the-welder-shortage-with-technology

Moll, I. (2021). The myth of the fourth industrial revolution. *Theoria*, *68*(167), 1–38. https://doi.org/10.3167/th.2021.6816701

NCCER. (2015). *Welding level 1 trainee guide -- hardcover* (5th ed.). Pearson.

Palani, P. K., & Murugan, N. (2006). Modeling and simulation of wire feed rate for steady current and pulsed current gas metal arc welding using 317L flux-cored wire. *The International Journal of Advanced Manufacturing Technology*, *34*(11-12), 1111–1119. https://doi.org/10.1007/s00170-006-0678-0

Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2021). User acceptance of augmented reality welding simulator in engineering training. *Education and Information Technologies*, *27*(1), 791–817. https://doi.org/10.1007/s10639-020-10418-7

Philbeck, T., & Davis, N. (2019, January 21). The fourth industrial revolution: Shaping a new era. *Journal of International Affairs.* https://jia.sipa.columbia.edu/fourth-industrial-revolution-shaping-new-era

Phillips, R. J. (2000). Digital technology and institutional change from the gilded age to modern times: The impact of the telegraph and the internet. *Journal of Economic Issues*, *34*(2), 267–289. https://doi.org/10.1080/00213624.2000.11506266

Piotrowski, C., & King, C. (2020). Covid-19 pandemic: Challenges and implications for higher education. *Education*, *141*(2), 61–66.

Porter, N. C., Cote, J., Gifford, T. D., & Lam, W. (2006). Virtual reality welder training. *Journal of Ship Production*, *22*(03), 126–138. https://doi.org/10.5957/jsp.2006.22.3.126

Price, A. H., Kuttolamadom, M., & Obeidat, S. (2019, January 30–February 1). *Using virtual reality welding to improve manufacturing process education* [Paper presentation]. 2019

Conference for Industry and Education Collaboration, American Society of Engineers, New Orleans, LA, United States.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Rampaul, H. (2003). *Pipe welding procedures* (2nd ed.). Industrial Press.

Ravid, R. (2020). *Practical statistics for educators* (6th ed.). Rowman & Littlefield Publishers.

Rose, M., Pate, M. L., Lawver, R. G., Warnick, B. K., & Dai, X. (2015). Assessing the impact of sequencing practicums for welding in agricultural mechanics. *Journal of Agricultural Education*, *56*(1), 92–102. https://doi.org/10.5032/jae.2015.01092

Salas, E., Bowers, C. A., & Rhodenizer, L. (1998). It is not how much you have but how you use it: Toward a rational use of simulation to support aviation training. *The International Journal of Aviation Psychology*, *8*(3), 197–208.

Seccombe, K. (2017). *Exploring marriages and families* (3rd ed.). Pearson Education.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2001). *Experimental and quasi-experimental designs for generalized causal inference* (2nd ed.). Cengage Learning.

Shankhwar, K., Chuang, T.-J., Tsai, Y.-Y., & Smith, S. (2022). A visuo-haptic extended reality-based training system for hands-on manual metal arc welding training. *The International Journal of Advanced Manufacturing Technology*, *121*(1-2), 249–265. Retrieved June 17, 2022, from https://doi.org/10.1007/s00170-022-09328-4

Siemens, G. (2005). *Connectivism: A learning theory for the digital age*. Pressbooks. https://lidtfoundations.pressbooks.com/chapter/connectivism-a-learning-theory-for-the-digital-age/

Srinivasa, A. R., Jha, R., Ozkan, T., & Wang, Z. (2020). Virtual reality and its role in improving student knowledge, self-efficacy, and attitude in the materials testing laboratory. *International Journal of Mechanical Engineering Education*, *49*(4), 382–409. https://doi.org/10.1177/0306419019898824

Steffen, J. H., Gaskin, J. E., Meservy, T. O., Jenkins, J. L., & Wolman, I. (2019). Framework of affordances for virtual reality and augmented reality. *Journal of Management Information Systems*, *36*(3), 683–729. https://doi.org/10.1080/07421222.2019.1628877

Stone, R. T., McLaurin, E., Zhong, P., & Watt, K. (2013). Full virtual reality vs. integrated virtual reality training in welding. *Welding Journal*, *92*, 168s–174s.

Stone, R. T., Watts, K. P., & Zhong, P. (2011). Virtual reality integrated welder training. *Welding Journal*, *90*, 136s–141s.

Tanjung, K., Nainggolan, F., Siregar, B., Panjaitan, S., & Fahmi, F. (2020). The use of virtual reality controllers and comparison between vibe, leap motion, and sensor gloves applied in the anatomy learning system. *Journal of Physics: Conference Series*, *1542*(1), 012026. https://doi.org/10.1088/1742-6596/1542/1/012026

Teeravarunyou, S., & Poopatb, B. (2009). Computer-based welding training system. *International Journal of Industrial Engineering*, *16*(2), 116–125.

Teixeira, K., & Pimentel, K. (1993). *Virtual reality: Through the new looking glass*. The McGraw-Hill Companies.

Triola, M. F. (2022). *Elementary Statistics* (14th ed.). Pearson.

Trust, T., Woodruff, N., Checrallah, M., & Whalen, J. (2021). Educators' interests, prior knowledge and questions regarding augmented reality, virtual reality, and 3D printing and modeling. TechTrends. https://doi.org/10.1007/s11528-021-00594-9

U.S. Bureau of Labor Statistics. (2022, April 28). *Welders, cutters, solderers, and brazers*. Occupational Outlook Handbook. Retrieved June 12, 2022, from https://www.bls.gov/ooh/production/welders-cutters-solderers-and-brazers.htm#tab-2

Vince, J. (1998). *Essential virtual reality fast*. Springer London. https://doi.org/10.1007/978-1-4471-1263-1

Wang, Q., Jiao, W., Yu, R., Johnson, M. T., & Zhang, Y. (2020). Virtual reality robot-assisted welding is based on human intention recognition. *IEEE Transactions on Automation Science and Engineering*, *17*(2), 799–808. https://doi.org/10.1109/tase.2019.2945607

Wells, T., & Miller, G. (2020). The effect of virtual reality technology on welding skill performance. *Journal of Agricultural Education*, *61*(1), 152–171. https://doi.org/10.5032/jae.2020.01152

Weman, K. (2012). *Welding processes handbook* (2nd ed.). Woodhead Publishing Limited. https://doi.org/10.1533/9780857095183

Whitchurch, G. G., & Constantine, L. L. (2008). Systems theory. In *Sourcebook of family theories and methods* (pp. 325–355). Springer. https://doi.org/10.1007/978-0-387-85764-0_14

White, S. A., Prachyabrued, M., Chambers, T. L., Borst, C. W., & Reiners, D. (2010). Low-cost simulated MIG welding for advancement in technical training. *Virtual Reality*, *15*(1), 69–81. https://doi.org/10.1007/s10055-010-0162-x

Whitney, S. J., & Stephens, A. K. (2014). *Use simulation to improve army welding training effectiveness* (DSTO-TR-2997) [Unclassified Report]. Australian Government; Defence Sciences and Technology Organisation; Land Division; 2nd Joint & Operations Analysis Division.

Wilson, B. A. (1997). Cognitive rehabilitation: How it is and how it might be. *Journal of the International Neuropsychological Society*, *3*(5), 487–496. https://doi.org/10.1017/s1355617797004876

Xia, J., Huang, D., Li, Y., & Qin, N. (2020). Iterative learning of human partner's desired trajectory for proactive human-robot collaboration. *International Journal of Intelligent Robotics and Applications*, *4*(2), 229–242. https://doi.org/10.1007/s41315-020-00132-5

Xu, J., & Moreu, F. (2021). A review of augmented reality applications in civil infrastructure during the 4th industrial revolution. *Frontiers in Built Environment*, *7*. https://doi.org/10.3389/fbuil.2021.640732

Zajtchuk, R., & Satava, R. M. (1997). Medical applications of virtual reality. *Communications of the ACM*, *40*(9), 63–64. https://doi.org/10.1145/260750.260768

Appendix A

Two Sample T Hypothesis Test for Research Question 1

Table A1

Traditional and XR Combined Groups: Difference Between Means Hypothesis T Test

Difference	Sample Diff.	Std. Err.	DF	T-Stat	P-value
$\mu_1 - \mu_2$	26.9	7.548289	10.233991	3.5637215	0.0025

Note:

μ_1 : Mean of Raw Score where "Treatment Group"="TRADITIONAL"

μ_2 : Mean of Raw Score where "Treatment Group"="XR COMBINED"

$\mu_1 - \mu_2$: Difference between two means

$H_0 : \mu_1 - \mu_2 = 0$

$H_A : \mu_1 - \mu_2 > 0$

Appendix B

Two Sample T Hypothesis Test for Research Question 2.

Table B1

Traditional and XR Before Groups: Difference Between Means Hypothesis T Test

Difference	Sample Diff.	Std. Err.	DF	T-Stat	P-value
$\mu_1 - \mu_2$	14.8	10.97816	4.2644114	1.3481312	0.1224

Note.

μ_1 : Mean of Raw Score where "Treatment Group"="TRADITIONAL"

μ_2 : Mean of Raw Score where "Treatment Group"="XR BEFORE"

$\mu_1 - \mu_2$: Difference between two means

$H_0 : \mu_1 - \mu_2 = 0$

$H_A : \mu_1 - \mu_2 > 0$

Appendix C

Two Sample T Hypothesis Test for Research Question 3

Table C1

Traditional & XR After Groups: Difference Between Means T Test

Difference	Sample Diff.	Std. Err.	DF	T-Stat	P-value
$\mu_1 - \mu_2$	39	7.2814834	4.624304	5.3560515	0.0019

Note.

μ_1 : Mean of Raw Score where "Treatment Group" = "TRADITIONAL"

μ_2 : Mean of Raw Score where "Treatment Group" = "XR AFTER"

$\mu_1 - \mu_2$: Difference between two means

$H_0 : \mu_1 - \mu_2 = 0$

$H_A : \mu_1 - \mu_2 > 0$

Appendix D

Two Sample T Hypothesis Test for Research Question 4

Table D1

XR Before & XR After Groups: Difference Between Means T Test

Difference	Sample Diff.	Std. Err.	DF	T-Stat	P-value
$\mu_1 - \mu_2$	24.2	12.877111	6.862804	1.8793034	0.0516

Note.

μ_1 : Mean of Raw Score where "Treatment Group" = "XR BEFORE"

μ_2 : Mean of Raw Score where "Treatment Group" = "XR AFTER"

$\mu_1 - \mu_2$: Difference between two means

$H_0 : \mu_1 - \mu_2 = 0$

$H_A : \mu_1 - \mu_2 > 0$

Appendix E

IRB Approval

irb

Active

RacerMail

3 of 17

Fwd: Application to Conduct Research at Mississippi Gulf Coast Community College [#46] Inbox

Randy Wilson <rwilson6@murraystate.edu>
to me

Oct 28, 2022, 9:26 AM

Well…I thought I sent this last week. Not sure what happened. You're good to go.

Sorry for the delay.
RW

Sent from my iPhone

Begin forwarded message:

From: MSU IRB <msu.irb@murraystate.edu>
Date: October 24, 2022 at 3:40:19 PM CDT
To: Randal Wilson <rwilson6@murraystate.edu>
Subject: Re: Application to Conduct Research at Mississippi Gulf Coast Community College [#46]

I will accept this approval since it's all being done at their institution. This is IRB #23-069 - there is no approval letter to attach since the MGCCC approval is being used.

Monica can begin her project as long as she complies with the MGCCC approval.

Thanks!

On Mon, Oct 24, 2022 at 10:17 AM Randal Wilson <rwilson6@murraystate.edu> wrote:

Jonathan - Monica has gotten IRB approval from her institution, Mississippi Gulf Coast Community College, on her project (see email below). Is their review sufficient or does she need to submit an application to us as well?

Thx.
RW

Randal H. Wilson, Ph.D.
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