IDENTIFYING THE EFFECTS OF INTEGRATING VIRTUAL REALITY TECHNOLOGY INTO BEGINNING WELDER TRAINING

by

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DEDICATION

This work, and thesis, is dedicated to my late great-grandmother and Southwest Texas State Alumni, Lillian Broom, who served as a constant role model throughout my life and inspired me to pursue the dreams I never thought possible.

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Thank you to my family members who have always supported my endeavors, especially to my mother Sara, who always reminded me that pain (and research) is only temporary. Thank you to all the friends who stayed by my side, shared my struggles, and continued to support me through challenging times. Thank you to my partner Travis, for always ensuring my cup of coffee is full. And thank you to my mentors and Texas State Agricultural Mechanics research team for constantly pushing me to my limits and always believing in my capabilities. This work would not have been possible without all of you, and I am so grateful for having experienced this journey.

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I. GENERAL INTRODUCTION

This chapter will set the stage for virtual reality (VR) technology and its role as a tool in educational and training settings, specifically within the welding industry. Traditionally, welding training methods are quite costly and time-intensive, two characteristics that threaten the welding industry as there exists a projected welder deficit of roughly 366,000 welders by the year 2026 (American Welding Society, 2022; Whitney & Stephens, 2014). The need for adeptly trained welders will continue to increase, meaning welding training will need to pivot to a more cost- and time-efficient model, while still providing meaningful learning (American Welding Society, 2022). Considering where improvements can be made within the welding training sector, technology can provide a valuable solution (Fast et al., 2004). More specifically, VR technology implementation can address many of the common issues arising in welding training methods (Wells & Miller, 2020).

Background

Innovation and adaptive technologies have served as tools for humankind, utilized for centuries in order to create more structured, enhanced lifestyles (Heinert & Roberts, 2016). VR technologies, first adapted in 1968, have been increasingly developed over the past few decades (Virtual Reality Society, 2020). Offering a completely safe and realistic experience, these VR technologies and training systems have been adapted for and widely used in various fields across the world, most notably for surgical training, military combat training, aviation, advanced and large machinery operation training (Bailenson et al., 2008; Karagiannis et al., 2021).

In recent years, engineers have adapted VR technology to teach and simulate the highly valued skill of welding through training simulations. These VR training simulations offer several benefits to the welding industry, namely by means of material and consumable savings. Even though VR welding training simulations cut levels of material usage drastically, VR technology likewise allows for a decreased amount of required training time while simultaneously increasing the level of understanding and skill acquisition (Stone et al., 2011; Wells & Miller, 2020). This unique aspect of VR technology may allow for faster acquisition of welding performance skills and thus faster, more efficient overall welding training when compared to traditional welding training methods (Kneebone, 2005).

Statement of the Problem

Throughout the past decade, a serious dilemma within the welding industry has been realized. Though the average age of a professional welder in America is roughly 40 years old, as of 2020 almost half (about 44%) of the welding workforce is 45 years or older (Buel, 2021). Therefore, a large portion of the welding workforce is projected to retire within the next few years, resulting in an insufficient supply of skilled welders. Many industries rely on welders to fabricate and manufacture materials essential to the function of our society's infrastructure. With a projected deficit of about 366,000 welders within the next five years, the industry will need to find alternative methods to train proficient welders effectively and efficiently (American Welding Society, 2022).

It is clear that VR technologies have the potential to provide a cutting-edge solution for the welding industry by decreasing training times, increasing the safety of the training environment, and enhancing the learning experience users receive (Benson et al., 2016). Unfortunately, effects of supplementing beginning welders with VR technologies in welding training has been studied minimally (Wells & Miller, 2020). This study intends to explore the effects of implementing VR welding simulation technology into welding training, as well as the effects of employing personalized feedback cues within the virtual environment.

Purpose and Objectives

The purpose of this research is to explore the effects of implementing VR welding training simulations into the training of beginning welders. This study also aims to identify the professional development needs of beginning welders by employing virtual parameter cues using the Lincoln Electric VRTEX 360 virtual welding simulator. The VRTEX 360 welding simulator measures welding skill performance by tracking five weld parameters. The VRTEX 360 assesses a user's weld, assigns scores to each of the five welding parameters, and determines an overall score of the weld. The main objective guiding this study, utilizing the VR welding simulation, is to identify participants' weld parameter scores achieved with and without the respective virtual parameter cue assistance. Beginning welders often struggle with the five welding parameters as they require fine-tuned techniques. This study will help to identify effects of integrating VR technology into beginning welder training, and the most challenging parameter(s) to master in welding training.

Assumptions

Prior to the implementation of this research, two assumptions were made. The first assumption being that the random assignment of participants to a welding sequence training group would control for any extraneous circumstances, such as participants having more/less knowledge of the welding process or theory. It was also assumed that participants' maturity levels, prior welding, or VR experience, would not affect their ability to learn how to weld properly using the VR welding training simulator.

Limitations

A limitation that arose during this research was the level of instruction quality throughout. This study was conducted over the course of three semesters, and although research instructors overseeing the welding training sessions remained consistent, their teaching abilities may have inadvertently improved. The research instructors provided participants with script-supported welding lessons, however the instructors also provided personalized feedback to each of the participants throughout the training process. As each semester progressed, the instructors' abilities to provide helpful advice and tips improved, meaning the participants may have received different qualities of welding training. Another limitation within this study was related to the study sample. Participants for this study were students enrolled in Texas State University's Introduction to Agricultural Engineering (AG 2373) course, and because participants were from a variety of academic majors, some may have possessed more welding knowledge or experience than other participants.

Definition of Terms

Throughout this manuscript, various welding terms are used in order to describe the multitude of affects that VR welding training simulations may have on beginning welders, and ultimately the future of the welding industry. Below is a thorough yet non-comprehensive list of welding terms used throughout this paper and their respective definitions.

1. **2F**: “a fillet weld made in the horizontal position” (Bowditch et al., 2017, P. 603)
2. **Certified Welding Inspector (CWI)**: an individual who, in accordance with American Welding Society (AWS) standards, is certified to successfully “determine if a weldment meets the acceptable criteria of a specific code, standard, or other document” (American Welding Society, 2007, p. vii)
3. **Fillet weld**: “an inside corner weld made at the intersection of two surfaces that form a right (90°) angle” (Bowditch et al., 2017, p. 600)
4. **Gas metal arc welding (GMAW)**: “an arc welding process that uses a continuously fed consumable electrode or wire and a shielding gas” (Bowditch et al., 2017, p. 602)
5. **Educational technology**: “the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources” (Januszewski & Molenda, 2008, p. 1)
6. **Personal protective equipment**: “the eye, ear, head, hand, arm, leg, foot, and general body protective equipment used by each individual on the job” (Bowditch et al., 2017, p. 609)
7. **Shielding gas**: “a gas, usually inert, that is used to blanket the welding area and prevent contamination from the air” (Bowditch et al., 2017, p. 613)
8. **Virtual reality (VR)**: “a three-dimensional, computer-generated environment which can be explored and interacted with by a person” (Virtual Reality Society, 2020).

9. **VRTEX® 360 Virtual Reality Welding Simulator**: A virtual reality weld training system that, through the use of instantaneous feedback, actual welding parameters, and realistic-appearing environments, can be used as a method of training for beginning and experienced welders (Lincoln Electric, 2017)
10. **Weld**: "the blending or mixing of two or more metals or nonmetals by heating them until they are molten and flow together" (Bowditch et al., 2017, p. 617)
11. **Welding:** "a joining process that produces coalescence of materials by heating them to the welding temperature" (Bowditch et al., 2017, p. 617)

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II. VIRTUAL REALITY IN WELDING EDUCATION:

A LITERATURE REVIEW

A paper prepared for submission to the *Journal of Agricultural Education*.

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Abstract

The welding workforce is facing a deficit of skilled welders, highlighting the industry's need to develop a more efficient and effective training method. Virtual reality (VR) technologies have been adopted to create VR welding simulations, intended for use in welding training. In this literature review, our purpose was to collect and analyze peer-reviewed research, published between 2012-2022, regarding VR technology applications in welding training. The concept of Blended Learning guided our research framework. In the context of welding, VR welding training is a relatively new training approach that functions as a blended learning environment. Our data collection resulted in a total of 31 articles, however, following analysis and coding, 13 articles were excluded, and 18 articles remained. Through a process of triangulation, we identified themes across existing research to highlight trends, recommendations for real-world welding practice, and recommendations for future research. Four main research themes emerged from the literature: *1. Comparison of Approaches, 2. VR as a Teaching Tool, 3. System Development, and 4. System Testing.* Six future research recommendations were identified and grouped, including the recommendation to compare virtual weld performance to live weld performances. Four real-world practice themes were identified, including the recommendation for instructors to develop their own knowledge and skills

[1] Though this manuscript was co-authored, more than 51% of the work was completed by Brittney H. Heibel

related to VR welding technology. From this review it is clear that there exist gaps in the existing literature, therefore recommendations are given for future research that relates to VR welding training.

Introduction

Welding is a critical sector of the global manufacturing and fabrication industries, including the automotive, construction, pipeline, and energy industries (American Welding Society, 2022). The welding workforce is currently facing a deficit of skilled workers, highlighting the need more effective and efficient welding training (American Welding Society, 2022). Various technological advances have been developed for welding training, including virtual reality (VR) welding training simulations (Liang et al., 2014). This paper explores existing research and literature investigating the use of VR technology in welding training and education settings.

Industry Challenges

As of 2020, 44% of the U.S. welding workforce was workers aged 45 years and older (Buel, 2021). Accordingly, it is expected that much of the welding workforce will soon retire, resulting in a projected workforce deficit of approximately 366,000 skilled welders by 2024 (American Welding Society, 2022). As countless economies and industries rely on welders to manufacture and fabricate products, welding industry leaders (e.g., Career and Technical Education [CTE] program directors, Student-Based Agricultural Education [SBAE] instructors, and welding instructors) will need to train highly proficient welders at an expedited rate to address the projected deficit (American Welding Society, 2022)

In training highly proficient workers quickly, an obstacle that welding industry leaders and trainers will need to overcome is the inherently difficult nature of traditional welding training which first provides welding knowledge through lessons, typically in classroom settings, then introduces hands-on learning (Lincoln Electric, 2022). In the initial lessons, trainees learn about welding machines and equipment, proper personal protective equipment (PPE), safety protocols, welding processes and respective consumables, metallurgy concepts, welding techniques, and welding parameters (Lincoln Electric, 2022; Whitney & Stephens, 2014). Once trainees are familiarized with these concepts, they begin hands-on learning by performing 'practice welds', traditionally in workshop settings. In traditional welding workshops, trainees are placed into isolated weld booths for safety (Lincoln Electric, 2022). Trainees are then asked to perform certain weld processes and specific configurations. Trainees present their completed welds to instructors who then predict what the imperfections are and where they originated from (Lincoln Electric, 2022). Weld imperfections result from many mistakes including incorrect travel speed, short arc length, and mis-positioning (Wells & Miller, 2020b). Instructors then suggest techniques and tips for the trainee to improve their weld performance. This cycle of repetitive weld practice continues until the trainee learns and acquires the skills of producing high-quality welds (Ilyashenko et al., 2019).

Traditional welding training creates many problems, particularly those related to economic and complexity issues (White et al., 2010). Economic drawbacks arise from traditional welding training because of the especially costly training. Welding training requires a mass amount of consumable material and energy in the form of metal (e.g., steel, aluminum, titanium, cast iron, copper, brass), natural gas (e.g., argon, helium, hydrogen, oxygen, carbon-dioxide, and nitrogen), welding wire (e.g., manganese, silicon, titanium, aluminum, copper), consumable and non-consumable electrode rods (e.g., mild-steel, cast iron, stainless steel, high-tensile steel, copper, bronze, brass) and electrical power consumption (Adams et al., 2022). Along with the reliance on expensive materials and consumables, welding machines also require frequent maintenance and care which requires time, manpower, and, in many cases, monetary inputs ranging from $40 to $200+ (Miller Electric Mfg LLC, 2005).

The complexity of welding also presents challenges in traditional welding training. Welding is a difficult and precise skill to master; training requires extended periods of practice to master the concepts, performance, and troubleshooting that competent welder require (Lincoln Electric, 2022). Traditional welding training also demands a high level of self-assessment of welding performance (Whitney & Stephens, 2014). Traditional welding training may not be the most effective approach for everyone, as some learners require alternative methods for understanding the complex concepts, such as those that characterize welding (Kulkarni et al., 2022). Traditional welding training also requires considerable mentorship and instructor intervention for trainees who do not excel at self-assessment and troubleshooting (Lincoln Electric, 2022). Faced with the surge of retiring welding professionals, the number of qualified welding instructors will likely not be sufficient to train and provide adequate mentorship to the number of highly skilled welders the industry demands (Ipsita et al., 2022).

Virtual Reality Welding Simulations

In response to the pressing need to develop a large and highly trained workforce and to address the challenges associated with traditional welding training, there has been research investigating the incorporation of various VR technology training applications into welding training programs and courses (Dalto, 2010; Stone et al., 2013; Wells & Miller, 2020a; Wells & Miller, 2020b). VR technologies create fully immersive artificial or computer-generated virtual environments (VEs) equipped with visual, audial, tactile, and other modalities (Benson et al., 2016). VR simulations are typically implemented using oculus goggles, head-mounted displays (HMDs), sensor-filled gloves, and/or haptic input attachments. These devices aid the system in providing a complete VE where users can perform tasks. VR technology has most commonly been adapted as a tool for medical, military, aviation, automotive, and space training purposes; however, more recently, VR technology has also been adapted for the welding industry (Hasan et al., 2017). Virtual cues are one feature of VR welding technologies that can aid welders in understanding complex concepts of welding (Stone et al., 2013). Virtual cues display the welding parameters that determine a high-quality weld. Another feature of VR welding technologies is the instant weld quality grading (Lincoln Electric, 2022). The instant, personalized feedback allows for faster training procedures than that of traditional welding training, while still providing meaningful learning (Stone et al., 2013).

Conceptual Framework

The Engagement in Blended Learning Environments conceptual framework was used to guide our study (Halverson & Graham, 2019). This conceptual framework explains that educational outcomes, academic achievement, and satisfaction are directly correlated to the learners' level of engagement in their blended learning environments. Blended learning environments utilize increased flexibility and personalization, opportunities for interaction, and technical advantages (e.g., online learning, simulations, gamification) to maximize engagement (Halverson & Graham, 2019). A learners' engagement level depends on the cognitive and emotional energy they dedicate to their lesson or activity. The more cognitive and emotional energy dedicated, the more likely the learner is to achieve academic success and satisfaction.

In the context of welding, VR welding training is a relatively new training approach that functions as a blended learning environment. Learners are provided a unique learning environment in the VE and are given personalized feedback regarding their welds from the VR welding simulation. Interactivity allowed by the VR welding simulation requires more understanding and involvement from both the learners and the observers during the welding training.

Purpose and Objectives

The purpose of this literature review was to collect and analyze peer-reviewed, published research regarding VR technology applications in welding training and education. In this review, we identified themes across existing research to highlight trends, recommendations for real-world welding practice using VR technology, and recommendations for future research. The objectives of this literature review were to:

1. Determine the number of existing research articles published between 2012-2022 regarding VR technology implementation in welding training.
2. Determine which research topics are prevalent within the existing literature regarding VR technology implementation in welding training.
3. Identify and interpret the key themes prevalent within the existing literature regarding VR technology implementation in welding training and outline recommendations for practice and future research.

Methods

This literature review gathered, quantified, and interpreted existing research focused on VR technologies in welding education and training environments. The design was partially adapted from Kovar and Ball (2013) and three strategies were used: 1) definitive search strategies, 2) explicit inclusion criteria, and 3) source analysis and categorization.

Search Strategies

To collect articles for this review, we searched various electronic databases, including Google Scholar, Scopus, IEEE Xplore, Education Resources Information Center, Web of Science, ResearchGate, and academic journals (i.e., Journal of Agricultural Education, Welding Journal). Combinations of the keywords “virtual reality”, “welding”, “welding training”, and “VR applications” were used to identify articles. The article search began 12 July 2022 and concluded 2 September 2022.

Inclusion Criteria

Inclusion criteria for our search encompassed specific populations, interventions, publishing dates, and publishing format (Table 2.1). Populations were welding trainees, welding and non-welding students, and welding and non-welding trainers/instructors, without age or experience limitations. Interventions were VR technologies and applications incorporated into welding educational and training environments. Literature was peer-reviewed and published as a manuscript in a refereed journal between 2012 and 2022; conference proceedings, theses/dissertations, and patents were excluded.

Table 2.1. Inclusion and Exclusion Criteria for Literature Collection

Inclusion criteria	Exclusion criteria
English language publication	Non-English language publication
Publication regarding a welding training/education environment	Publication not involving a welding training/education environment
Publication with listed references/sources	Publication without references/sources
Publication investigating immersive virtual reality technology	Publications using augmented reality or robotic welding technology
Publications and reports in peer-reviewed journals	Conference proceedings, theses/dissertations, patents

Analysis and Categorization

Article analysis and categorization involved an initial screen stage and a coding stage. For screening, the articles' title and abstracts were cross-referenced with established inclusion/exclusion criteria. If the titles and abstracts did not contain adequate information for screening, the introduction, methods, discussion, and conclusion sections were combed for further consideration. Our data collection resulted in a total of 31 articles related to the investigation of VR technology implementation in a welding training and educational setting. Following the literature analysis and coding stages, 13 articles were excluded. Articles with noticeable grammatical errors, misconstrued data, and/or misrepresented data were excluded from further analyses. Other article exclusions included robotic welding technology research focuses, conference proceedings publications, predatory journal publications, and in two cases, plagiarism. Once final article exclusions were made, 18 articles remained.

The coding stage involved full-text evaluations where three researchers independently identified key findings, themes, research methods, and recommendations of the collected articles (*N*=18). As recommended by Kovar and Ball (2013), peer debriefings were conducted to externally review the researchers' findings. Researchers discussed their independent coding/theming of the articles and justified their reasoning. Following the peer debriefings, researchers then decided which suggested code/theme best represented each article, as well as which research and practice recommendations were presented by each article. This method of data triangulation corroborates findings and increases the reliability of our results.

Results and Discussion

Research Topic Themes

From the analysis and coding of the collected articles (*N*=18), four research topic themes were identified: *1. Comparison of Approaches, 2. VR as a Teaching Tool, 3. System Development, and 4. System Testing* (Table 2.2). In the case of one theme, *2. VR as a Teaching Tool,* three sub-themes emerged: *2.1 Performance Outcomes, 2.2 User Perceptions, and 2.3 User Experiences.* Some articles were coded for multiple themes; accordingly, the number of articles examined is less than the number of themes coded for. For example, an article could code for both *1. Comparison of Approaches* and *3. System Development*.

Table 2.2. Identified Research Topic Themes and Sub-themes for Virtual Reality (VR) Welding Literature Analysis, Theme and Sub-theme Descriptions, and Number of Articles Categorized into Themes (*N*=18)

Theme	Description	Articles (*n*)
1. Comparison of Approaches	Research comparing implementation of VR welding training methods to other forms of welding training	4
2. VR as a Teaching Tool	Research investigating the teaching aspects and outcomes of VR technology implementation in welding training	14
2.1 Performance Outcomes	Research that specifically evaluates performance outcomes from VR technology implementation in welding training	8
2.2 User Perceptions	Research that investigates user perceptions of VR technology (e.g., acceptance, dislike)	8
2.3 User Experiences	Research that investigates user experiences of VR users (e.g., frustration, comfort)	4
3. System Development	Research that presents and discusses VR welding training system development	6
4. System Testing	Research that aims to test various aspects of VR welding training system(s)	5

The first theme, identified in four articles, was *1. Comparison of Approaches*. Articles with this theme compared and contrasted different aspects and outcomes between welding training methods. The comparison of VR training to traditional welding training emerged in three articles that investigated the difference between full VR welding training methods and traditional live welding training methods (Liang et al., 2014; Shankhwar & Smith, 2022; Shankhwar et al., 2022). By comparing traditional welding training methods to VR training methods, advantages were identified, such as material savings (Liang et al., 2014; Shankhwar & Smith, 2022; Shankhwar et al., 2022), increased learner satisfaction (Shankhwar & Smith, 2022; Shankhwar et al., 2022), and training time savings (Liang et al., 2014). Another key finding in these articles were that trainees who underwent VR training experienced less mental and temporal demands, as well as less frustration, than those who underwent traditional training (Liang et al., 2014; Shankhwar & Smith, 2022; Shankhwar et al., 2022). One article investigated a full VR welding training method against a VR integrated (partially VR, partially live) or "VRI" training method (Byrd et al., 2018). This study used simple weld configurations (2F, 1G, 3F, and 3G) and the Gas Metal Arc Welding process to evaluate welders' live and virtual abilities. Results from this study demonstrated that welding training can successfully be presented in the virtual environment; however, it cannot replace the actual act of welding. Therefore, live welding practice will always be required. Understanding the effects of blended learning such as VRI training is crucial to optimizing welding training (Byrd et al., 2018).

The second theme identified in 14 of the 18 articles was *2. VR as a Teaching Tool* which encompasses research investigating the teaching aspects of VR technology implementation in a welding training or learning setting. Due to the high volume and diversity of articles, this theme included three sub-themes: *2.1 Performance Outcomes, 2.2 User Perceptions,* and *2.3 User Experiences*.

Theme *2.1 Performance Outcomes*, emerged from eight articles that evaluated the user performance outcomes of VR welding training methods (Byrd et al, 2015; Byrd et al., 2018; Huang et al., 2020; Liang et al., 2014; Shankhwar & Smith, 2022; Shankhwar et al., 2022; Stone et al., 2013; Wells & Miller, 2020b). Performance outcomes encompassed weld quality scores, welding certification rates, welding parameter scores, dexterous abilities, and pre- and post-knowledge tests. Six of the articles examined various performance outcomes for beginning welders using the VR technology (Byrd et al., 2018; Huang et al., 2020; Shankhwar & Smith, 2022; Shankhwar et al., 2022; Stone et al., 2013; Wells & Miller, 2020b). Four articles reported an increase in welding parameter scores and certification rates following virtual welding training (Byrd et al., 2018; Huang et al., 2020; Stone et al., 2013; Wells & Miller, 2020b). Pre- and post-VR welding training knowledge tests report that participants gained more welding knowledge from the training (Shankhwar & Smith, 2022; Shankhwar et al., 2022). Five of the eight articles demonstrated that positive learning outcomes occurred as a results of VR welding training in the form of increased welding scores (Huang et al., 2020; Liang et al., 2014; Shankhwar et al., 2022; Stone et al., 2013; Wells & Miller, 2020b).

Theme *2.2 User Perceptions*, emerged from eight articles that examined the perceptions of students, teachers, and beginning and expert welders from integrating VR technology into welding training methods (Chung et al., 2020; Huang et al., 2020; Karstensen & Lier, 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019; Shankhwar

& Smith, 2022; Shankhwar et al., 2022; Wells & Miller, 2020a; Wells & Miller, 2022). Six of the articles collected the perceptions of beginning welders after using VR technology for welding training. These articles examined beginning welders' attitudes and acceptance towards VR welding training, learning satisfaction, usability of VR technology, and motivation for using VR technology in welding training (Chung et al., 2020; Huang et al., 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019; Shankhwar & Smith, 2022; Shankhwar et al., 2022; Wells & Miller, 2022). Beginning welders perceived VR welding training as highly usable for training, highly satisfying for learning welding constructs, and displayed positive attitudes towards VR welding training (Rodriguez-Martin & Rodriguez-Gonzalvez, 2019; Shankhwar & Smith, 2022; Wells & Miller, 2022). Two of the articles collected perceptions of welding and school-based agricultural education (SBAE) teachers (Karstensen & Lier, 2020; Wells & Miller, 2020a). Karstensen and Lier (2020) reported that SBAE teachers found value in using VR technology for welding training. Wells and Miller (2020a) reported that, although SBAE teachers felt a degree of uncertainty, they also felt VR would positively impact their welding training programs.

Theme 2.3 User Experiences emerged from four articles that evaluated the various experiences of students, teachers, and expert welders after welding training through VR methods (Chung et al., 2020; Feier & Banciu, 2021; Karstensen & Lier, 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019). User experiences were evaluated using questionnaires (cite), one-on-one and group interviews (cite), focus groups (cite), and journal entries (cite). Beginning welders undergoing VR welding training reported positive learning and usability experiences, high levels of learning satisfaction, and high levels of motivation to engage in the activity (Chung et al., 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019). Further, beginning welders realized an increased level of importance for weld quality than they did prior to training with VR (Rodriguez-Martin & Rodriguez-Gonzalvez, 2019). Experiences of beginning welders regarding VR welding training ergonomics were similar to that of traditional live welding, but it was noted that welding positions in the VE must reflect those in the live environment (Feier & Banciu, 2021). One article examined teachers' experiences from VR welding training and found that teachers faced initial challenges familiarizing themselves with VR welding technology but, once they developed a deeper understanding, they appreciated and valued VR (Karstensen & Lier, 2020).

The third theme identified was *3. System Development*. This theme emerged from six articles that proposed and/or developed a VR welding system (Benson et al., 2016; Chambers et al., 2012; Hadinejad-Roudi et al., 2021; Ismael et al., 2021; Shankhwar & Smith, 2022; Shankhwar et al., 2022). The articles discussed various immersive and mobile VR systems for inspecting welds, welding, and interacting in welding environments. Accuracy and fidelity of virtual weld penetration and simulation tracking were the main areas of focus for VR system developments (Benson et al., 2016; Chambers et al., 2012; Ismael et al., 2021). Further, all articles within the *3. System Development* theme concluded that VR welding systems aid in self-learning and learning enhancement (Hadinejad-Roudi et al., 2021; Shankhwar & Smith, 2022; Shankhwar et al., 2022).

The final theme, *4. System Testing*, emerged from five articles that evaluated recently developed VR systems (cite them here). Researchers tested their respective VR systems' fidelity of feedback (visual, audial, and haptic) and overall accuracy of virtual weld gun tracking (Benson et al., 2016; Ismael et al., 2021). A VR system tested by Shankhwar and Smith (2022) decreased the cognitive workload of users compared to that of traditional welding process. The same system also increased sense of presence in the VE compared to other VR systems (Shankhwar et al., 2022).

Research Recommendation Themes

All research recommendations from the collected articles were identified and grouped (*N*=18), outlined in Table 2.3. The most compelling and frequent theme, emerging from five articles, was the call for researchers to *1. Improve Fidelity Aspects of VR Welding Training Systems* (Benson et al., 2016; Byrd et al., 2018; Chambers et al., 2012; Shankhwar & Smith, 2022; Shankhwar et al., 2022). More specifically, previous researchers indicate there is a need to improve movement accuracy and for optic, visual, and haptic feedback (Benson et al., 2016; Chambers et al., 2012; Shankhwar & Smith, 2022; Shankhwar et al., 2022). Improving these aspects is intended to ensure VR welding training accurately mimics traditional training.

Another research recommendation theme that emerged from the literature, present in four articles, was a call for future research to *2. Investigate the Effects of VR Technology as a Teaching Tool* (Byrd et al., 2015; Chambers et al., 2012; Wells & Miller; 2020b; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019). These articles recommended that future research investigate the sequencing of VR technology implementation. Limited research has examined the various sequencing options for VRI welding training methods and their effects. It was also recommended that the visual cues provided by VR be investigated for learning outcomes and effects (Byrd et al., 2015;

Chambers et al., 2012; Wells & Miller; 2020b; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019). Limited research has attempted to understand the effects of using visual cues and virtual overlays in VR welding environments.

Across the articles, two recommendations were made for future research to use VR technology to *3. Compare Live Weld Performances to Virtual Weld Performances* (Byrd et al., 2015; Wells & Miller, 2020b). These articles recommend that VR weld performances should be compared to live weld performances to determine if VR accurately reflects the live welding process. Research that compares a welder's virtual performance to their live performance could identify if a significant difference exists between the two.

The fourth research recommendation theme, *4. Explore Alternative Weld Configurations and Processes*, emerged from three articles (Chambers et al., 2012; Byrd et al., 2015; Wells & Miller, 2020b). These articles highlighted the importance of investigating the performance of more complex weld positions and configurations (e.g., 2G, 4F, 4G), as well as different weld processes (e.g., Shielded Metal Arc Welding, Fluxed Core Arc Welding, Gas Tungsten Arc Welding). Future research investigating these outcomes of utilizing VR welding training for these weld configurations and processes would lead to a deeper understanding of the VR technology's potential uses.

The fifth research recommendation theme, *5. Incorporate VR Training into Welding Training Programs,* emerged from two articles (Chung et al., 2020; Huang et al., 2020). It is recommended that the incorporation of VR technology into welding training programs take place and be investigated for learning outcomes and uses. No research implementing VR training into welding training programs exists, therefore an initial study is needed to identify results.

The final research recommendation emerged from just one article, *6. Measure the Effects of VR HMDs on Welder Comfort* (Feier & Benciu, 2021). No research investigates the effect of VR HMDs on a welder's ability to perform or comfortability, therefore it is recommended that future research determine if a significant impact is made by the VR HMDs.

Table 2.3. Research Recommendation Themes for Virtual Reality (VR) Welding Literature Analysis, Theme Descriptions, and Number of Articles Categorized into Themes (*N*=18)

Theme	Description	Articles *(n)*
1. Improve VR system fidelity	Accuracy of optic, visual, or haptic feedback; system tracking of virtual weld gun; accuracy of weld pools	5
2. Investigate VR as a teaching tool	Sequencing of VR technology implementation; effects of virtual cue use	4
3. Compare live weld performances to virtual weld performances	Determining if VR accurately represents the live process of welding	2
4. Explore alternative weld processes and configurations	Incorporating complex weld configurations and processes into VR welding investigations	3
5. Incorporate VR training into welding training programs	Exploring the effects of utilizing VR in trade schools, welding programs, high schools, and universities	2
6. Measure the effects of VR Head-Mounted Displays (HMDs)	Determining if VR system HMDs have any effect on welders' ability to perform and comfort level	1

Real-World Practice Recommendation Themes

All real-world and practice recommendations from the collected articles were identified and grouped (*N*=18), outlined in Table 2.4. For real-world practice recommendations, the most prevalent theme that emerged in four articles from the collected literature was *1. Instructors Should Develop Skills to Implement and Use VR* in their training (Huang et al., 2020; Wells & Miller 2020a; Wells & Miller, 2020b; Wells & Miller, 2022). These articles all suggest that instructors who have the knowledge of how VR can be utilized can accurately integrate it in their program. Professional development workshops, seminars, and summer classes are potential opportunities for instructors to gain more experience and knowledge of VR welding technology (Wells & Miller, 2020b; Wells & Miller, 2022).

The second theme, that emerged from three articles, was *2. Promoting the Use of VR as a Support Teaching Tool*, specifically mobile VR technology (Byrd et al., 2015; Ismael et al., 2021; Wells & Miller, 2020b). This real-world practice theme suggests that VR is not a replacement for welding training, but as a supplemental teaching tool. Specific suggestions are that mobile VR can be a cost-effective method for integrating VR into training.

The third real-world practice theme that emerged during the literature review was *3. Use Correct Welding Positions When Welding in VR* (Feirer & Bancui, 2021; Stone et al., 2013). These articles suggested that welders undergoing any form of welding training, especially virtual, should always use the correct live welding positions. This process ensures the VR welding training will more accurately simulate live welding conditions.

The final real-world practice recommendation theme that emerged was *4. Utilize VR Technology to Evaluate New and Experienced Welders* (Byrd et al., 2015), emerging from one article. Welding program directors and instructors examining welders' skills in a VE could potentially have more in-depth and accurate understandings of a welder's performance abilities if they implemented VR training. By evaluating beginning welders through VR training systems, welding instructors have the potential to identify dexterous and physical abilities (Byrd et al., 2015).

Table 2.4. Real-World Practice Themes for Virtual Reality (VR) Welding Literature Analysis, Theme Descriptions, and Number of Articles Categorized into Themes (*N*=18)

Theme	Description	Articles (*n*)
1. Instructors Should Develop Their Own VR Technology Skills	By understanding the uses of VR technology, instructors can correctly implement it into their programs	4
2. Use VR As a Support-Teaching Tool, Specifically Mobile VR Technologies	Mobile VR technologies can be cost-effective options for a support teaching tool	3
3. Use Correct Welding Positions When Welding In VR	Correct welding positions will reinforce good performance in live welding settings	2
4. Use VR Systems to Evaluate Welder Performance	Welding instructors or program leaders can potentially have more accurate understanding of a welder's performance abilities	1

Discussion and Recommendations

Through this literature review, we collected and examined existing research that investigated the benefits, limitations, and outcomes of implementing VR technologies into welding training settings. The Engagement in Blended Learning Environments concept served as the framework for our study (Halverson & Graham, 2019). The concept describes how a learners' engagement level depends on the cognitive and emotional energy they dedicate to their lesson or activity. The more cognitive and emotional energy used, the more likely the learner is to obtain certain academic achievements and satisfaction.

The objectives for this review were to: 1) Determine the number of existing research articles published between 2012-2022 regarding immersive VR technology implementation in the welding training and education sector; 2) Determine which research questions and topics are prevalent within the existing literature; and 3) Identify and interpret the key themes prevalent within the existing literature's recommendations for practice and future research. Literature collected and analyzed were comprised of peer-reviewed research articles that were published between 2012 and 2022. Articles were analyzed to determine prevalent themes across research topics, research recommendations, and real-world practice recommendations. During this analysis, we excluded certain articles on the grounds of poor quality, inaccurate research, and/or plagiarism.

A total of 18 articles were included in this synthesis. Four major research topic themes were identified across the current research: *Comparison of Approaches, VR as a Teaching Tool, System Development,* and *System Testing.* The first research theme, *Comparison of Approaches*, which compared and contrasted different aspects and outcomes between welding training methods emerged from four articles. Three of these articles investigated the differences between full VR welding training methods and traditional live welding training methods (Liang et al., 2014; Shankhwar & Smith, 2022;

Shankhwar et al., 2022), and one investigated the differences between a full VR welding training method against a virtual reality-integrated (partially VR, partially live) training method (Byrd et al., 2018). Findings from these articles support the Engagement in Blended Learning Environments concept in that VR systems are used as supplemental learning experiences, rather than replacements for live welding.

The second research theme, *2. VR as a Teaching Tool,* emerged from 14 of the articles and encompassed research investigating the teaching aspects of VR technology implementation. This theme included three sub-themes: *2.1 Performance Outcomes, 2.2 User Perceptions,* and *2.3 User Experiences*. These articles are rooted in the Engagement in Blended Learning Environments concept as they all evaluate the learning aspects of VR welding systems. *2.1 Performance Outcomes*, emerged from eight articles that evaluated the performance outcomes of VR welding training methods (Byrd et al, 2015; Byrd et al., 2018; Huang et al., 2020; Liang et al., 2014; Shankhwar & Smith, 2022; Shankhwar et al., 2022; Stone et al., 2013; Wells & Miller, 2020b). *2.2 User Perceptions* emerged from eight articles that examined the perceptions of students, teachers, beginning and expert welders from integrating VR technology into welding training methods (Chung et al., 2020; Huang et al., 2020; Karstensen & Lier, 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019; Shankhwar & Smith, 2022; Shankhwar et al., 2022; Wells & Miller, 2020a; Wells & Miller, 2022). *2.3 User Experiences* emerged from four articles that evaluated the various experiences of students, teachers, and expert welders after welding training through VR methods (Chung et al., 2020; Feier & Banciu, 2021; Karstensen & Lier, 2020; Rodriguez-Martin & Rodriguez-Gonzalvez, 2019).

The third research theme, *3. System Development,* was present in six articles that created and presented VR welding systems (Benson et al., 2016; Chambers et al., 2012; Hadinejad-Roudi et al., 2021; Ismael et al., 2021; Shankhwar & Smith, 2022; Shankhwar et al., 2022). VR system functions, advantages, limitations, and potential uses are discussed throughout these articles. The fourth and final research theme, *4. System Testing,* emerged from five articles that tested their respective VR system for fidelity, accuracy, tracking ability, and sense of presence (Benson et al., 2016; Hadinejad-Roudi et al., 2021; Ismael et al., 2021; Shankhwar & Smith, 2022; Shankhwar et al., 2022).

Prevalent themes across the research and practice recommendations were also identified. Future research recommendation themes include recommendations to improve VR welding systems' fidelity and accuracy of tracking, investigate VR technology as a teaching tool, compare live welds to virtual welds, explore alternative weld processes and configurations, incorporate VR technology into welding training programs, and to measure the effects of VR HMDs. Recommendations for future real-world practices include recommendations for welding instructors to develop their own knowledge of VR technologies, recommendations to use VR systems to evaluate welder performance, use VR as a supportive teaching tool, and to use correct welding positions when virtually welding.

From this review it is clear that there exist gaps in the existing research, and therefore recommendations can be made for future research focused on VR welding training. First and foremost, in the process of analyzing the collected articles, we identified two articles that contained plagiarized literature and data from additional articles included in this synthesis. These articles were immediately excluded from the review; however, it is therefore recommended that researchers adhere to the guidelines of ethical research practices and maintain efforts to avoid publishing through predatory journals.

The second research recommendation stems from an existing gap in the literature. Research that involves the implementation of VR technology into any form of welding training or education should investigate the effects of VR as a supportive teaching tool. Three studies suggested that VR be used as a supplemental tool, and few studies examine the effects of such integration. It is recommended that these studies occur over an extended period, considering many studies are conducted over short, limited time periods (Byrd et al., 2018; Wells & Miller, 2020a). In the articles reviewed, the weld process and configurations performed were less complex. Byrd et al. (2015) and Stone et al. (2013) utilized the Shielded Metal Arc Welding process and the 2F, 1G, 3F, and 3G configurations, which are relatively simple compared to the other processes and configurations. Studies should investigate the various welding processes (e.g., Shielded Metal Arc Welding, Gas Metal Arc Welding, Gas Tungsten Arc Welding, Flux Cored Arc Welding) and the various weld configurations (e.g., T-joint, flat, groove, lap, pipe) and weld positions (e.g., horizontal, vertical, overhead).

Another gap within the existing literature is the understanding of barriers to VR technology integrations. Karstensen and Lier (2020) gathered the perceptions of two instructors and their two department heads regarding VR technology, Wells and Miller (2020a) gathered the perceptions of 90 SBAE instructors, but still more research is needed to establish a true understanding. Future research must explore the decision-making factors for welding instructors and teachers when considering VR technology implementation. Limited research identifies the barriers instructors face when attempting to obtain and/or integrate this technology. Such information would highlight areas in which aid can be provided to these instructors for enhancing their teaching methods with these Blended Learning Environment opportunities.

Finally, the most glaring gap in the existing literature is the lack of understanding of the virtual cues that can be employed in a virtual welding environment. Byrd et al. (2015), Chambers et al. (2012), and Wells and Miller (2020b) all recommended that the virtual parameter cues available in VR welding training be investigated. Virtual parameter cues can be engaged to aid users in correcting their mistakes, potentially leading them to develop problem-solving skills in the welding environment. No research exists that seeks to directly understand the effects of virtual cue implementation in a Blended Learning Environment such as that of virtual welding training. It is recommended that the effects and outcomes of virtual, visual, and audial cues be investigated and compared. Future research is recommended to explore these areas of interest in order to address the existing gaps in welding education literature and promote the advancement of welding training development.

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III. RESEARCH METHODS

This research was conducted over four-week timespans, a total of three separate times. Undergraduate students enrolled in the Introduction to Agricultural Engineering (AG 2373) course during the Spring ’21 (four total lab sections), Fall ’21 (three lab sections), and Spring ’22 (three lab sections) semesters at Texas State University served as our participants. As this is a part of a larger study, a randomized quasi-experimental design was used to randomly assign each lab section of participants to one of three sequence groups. All three sequence groups underwent identical welding training methods, simply at different rotations. Upon group assignment, all participants were asked to complete a paper-based demographics survey adapted from Wells and Miller (2020) that included questions regarding age, gender, dominant hand use for both general activities and welding activities, prior welding or VR experience, and other general demographic information. For this experiment, participants underwent three methods of welding training during Weeks One through Three: VR welding training, computer-based audio assisted (CBAA) welding training, and traditional live welding training. Each of the welding training methods utilized the gas metal arc welding (GMAW) process to perform single-pass 2F fillet welds on ¼” mild steel. Further training method descriptions are discussed below. During Week Four, participants underwent one final traditional live welding training session. At the conclusion of this final welding training session, participants were asked to submit their best live weld for quality grading. Table 3.1 illustrates the welding training sequence schedule for this study.

Table 3.1 Weld Process Training Sequences

Sequence Group	Weld Process Training for Week One	Weld Process Training for Week Two	Weld Process Training for Week Three	Weld Process Training for Week Four
Sequence Group One	VR	CBAA	Live	Live + Test Weld
Sequence Group Two	CBAA	Live	VR	Live + Test Weld
Sequence Group Three	Live	VR	CBAA	Live + Test Weld

Participants undergoing live weld process training, during Weeks One through Three, began their session with a 10-minute script-supported introductory explanation and demonstration of the GMAW process, given by the researcher instructors. Participants were then instructed to don their welding personal protective equipment (PPE) and tools (e.g., welding hood, gauntlet gloves, long-sleeve cotton t-shirt or jacket, welding pliers) for their individual weld booths. Participants were given 1 hour and 30 minutes to perform single-pass 2F welds using ¼" mild steel coupons and the GMAW process. Participants were encouraged to approach the research instructor with questions regarding the welding process.

Participants undergoing CBAA weld process training, during Weeks One through Three, were given a similar 15-minute script-supported introduction and demonstration of the Lincoln Electric REALWeld CBAA welding simulator. Following the introduction, participants were instructed to equip their welding PPE and tools. Participants were also provided score sheets to track their individual parameter and overall weld scores assigned by the REALWeld CBAA welding simulator, data not discussed in this manuscript. All students completed the REALWeld Weld Process

Training Protocol for this study, performing 2F filet welds using the GMAW process on ¼” mild steel coupons.

The VR weld process training, during Weeks One through Three, for this study involved a 10-minute script-supported introduction to the Lincoln Electric VRTEX 360 virtual welding simulator, given by research instructors. Participants were provided score sheets to track their individual parameter and overall weld scores assigned by the VRTEX 360. Each participant used the GMAW process to perform virtual single-pass 2F filet welds on the VRTEX 360 with an instructor present. Participants were required to complete three rounds of the VRTEX 360 Training Protocol established for this study. One round included four practice runs, each with different parameter cue assistance, and one test run with no cue assistance. Practice Weld One was performed using the Travel Speed cue, Practice Weld Two using the Position cue, Practice Weld Three using the Travel/Work Angle cue, and Practice Weld Four using the CTWD cue. The final Test Weld performed without cue assistance, as in real life. Table 3.2 displays the VRTEX 360 Training Protocol developed for this study.

Table 3.2 VRTEX 360 Virtual Reality (VR) Welding Training Protocol

Weld Pass	Visual/Audial Cue Employed
1. Practice Weld 1	Travel Speed Cue
2. Practice Weld 2	Position/Aim Cue
3. Practice Weld 3	Travel/Work Angle Cue
4. Practice Weld 4	CTWD Cue
5. Test Weld	None

The visual and audial parameter cues utilized in this research manifest in the virtual welding environment as gauges or icons, located at the tip of the user’s weld gun. The Travel Speed cue measures the speed at which a user moves their weld gun across their workpiece, presenting as an arrow gauge. If the user's travel speed is too slow, the cue's arrow slides into the yellow or red zones, and if proper travel speed is maintained, the cue's arrow remains in the green zone. The Travel/Work Angle cue is a combined cue that measures the angles in which a user holds their weld gun. Presenting as a target that moves as users adjust their horizontal (travel) and vertical (work) angles, the cue is meant to be positioned directly in the crosshairs to maintain proper weld gun angles throughout the weld process. The Position/Aim cue is a colored aim line, indicating the exact aim of the weld gun. The goal of a 2F filet weld is to fuse two pieces of metal together, therefore aiming directly at the joint is integral. A user maintaining proper aim at the joint of the weld will see a green aim line. If the user's aim drifts upward or downward, the cue line becomes yellow or red, indicating the need to reposition weld gun aim. Finally, the CTWD cue appears as a colored arrow that hovers above a barrier symbol. A user that holds their weld gun too close to the workpiece (causing weld puddle spatter) will see the arrow become red, directing the user to move farther away. A user that holds their weld gun too far from the workpiece (causing a disruption in the arc) will see the arrow become red, directing the user to move closer to the workpiece. CTWD is another elemental factor of welding as proper CTWD ensures effective weld penetration. Figure 3.1 shows the four parameter cues and how they are displayed within the virtual welding environment.

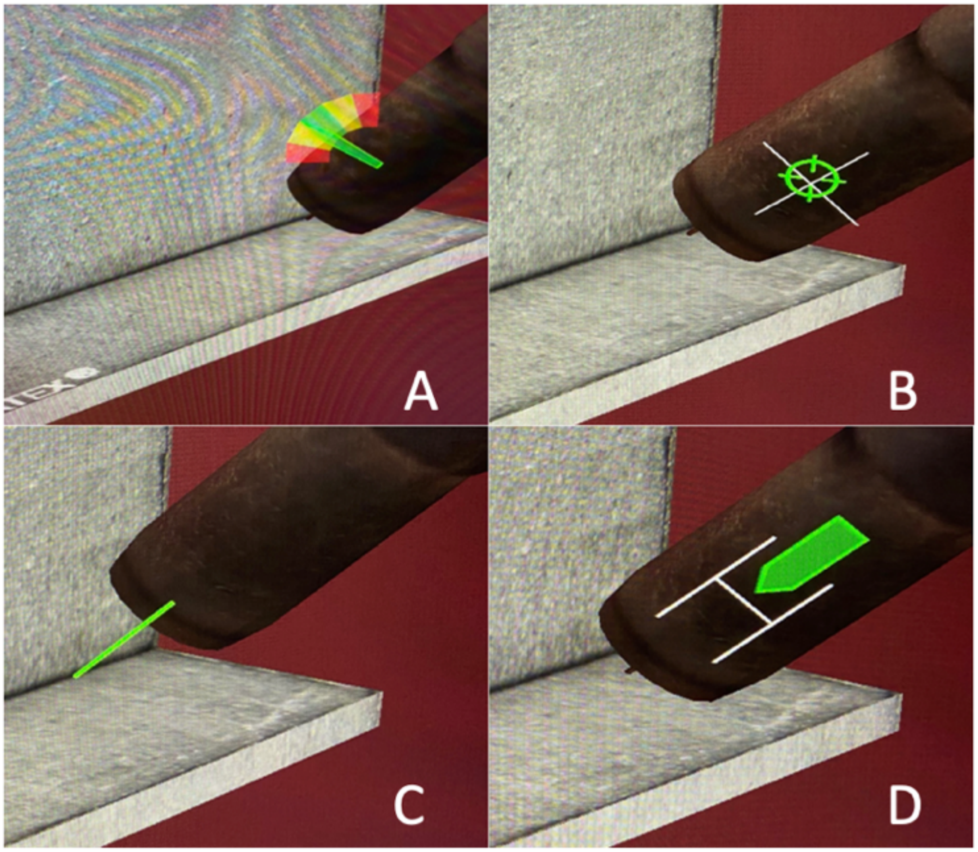

Figure 3.1. VRTEX 360 Virtual Parameter Cues. *Note.* Image A: Travel Speed cue; Image B: Work/Travel Angle cue; Image C: Position cue; and Image D: Contact To Workpiece Distance cue.

The VRTEX 360 provides scores, on a 100-point scale, for each of the welding parameters following every weld pass. Additionally, the VRTEX 360 averages the five welding parameter scores to compute an overall score for each weld pass. Figure 3.2 shows the score screen of the VRTEX 360. The overall score can be seen on the left of the screen, the VR weld shown in the center, and individual parameter scores are seen on the right.

Figure 3.2. VRTEX 360 Weld Score Screen.

Following each individual weld pass, participants select "End Pass" on the VRTEX 360 score screen, prompting the system to grade the weld based on the five parameters previously stated. Participants recorded their five parameter scores and their overall weld score for each of their weld passes, totaling 30 values per round. Following the completion of their first round, participants then rotated using the VRTEX 360 with their group members to complete all three rounds of VRTEX 360 weld process training.

During Week Four, all participants from all sequence groups underwent further traditional live welding training session. This training was performed with a research instructor and an American Welding Society (AWS) Certified Welding Inspector (CWI). Participants performed single-pass 2F filet welds on ¼" mild steel coupons, using the GMAW process. At the conclusion of the final training session, participants submitted their best live welds to be graded by the research instructor and the CWI. For this study, each sequence group underwent identical training protocols each week. Similarly, each experimental group underwent identical training protocols each semester.

Data collected from this research are interpreted into mean scores for each of the weld passes performed. Individual parameter scores for welds performed with and without the virtual parameter cues, and overall weld scores are collected. Limitations exist regarding the welding training session duration and VRTEX 360 weld-grade accuracy. The welding training session duration within this study does not reflect the training durations of welding trade schools, highlighting the need for future research to explore the long-term effects of implementing VR training methods. The weld grading parameters within the VRTEX 360 are reported to be tightly aligned with weld grading parameters used by AWS CWI's. However, further research is needed to establish full reliability of the VRTEX 360 weld grading system.

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IV. INTEGRATING VIRTUAL REALITY TECHNOLOGY INTO BEGINNING WELDER TRAINING SEQUENCES

A paper prepared for submission to the American Welding society *Welding Journal.*

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Abstract

Virtual reality (VR) technology is an advanced modern resource, commonly integrated into various forms of training. VR training simulations are customizable in that quality-grading parameter settings, physical environment, and user capacity can all be modified to personal or professional preference. In this study, VR technology training practices are utilized to enact meaningful learning. Meaningful learning is achieved by providing visual and audial cues within the virtual training environment, weld performance skill development, and ample skill practice time over a four-week span. This method of practice will reflect a new training style where beginning welders receive personalized feedback from both the VRTEX 360 virtual reality welding simulator and welding instructor. This training method benefits learners by expediting and enhancing their skill acquisition, adjusting their performance according to the various feedback they receive, and thereby experiencing meaningful learning. Results indicate that with each round of

[2] Though this manuscript was co-authored, more than 51% of the work was completed by Brittney H. Heibel

VR welding training participants' test weld scores continuously increased, as well as consistently scored 80% and higher. This enhanced performance of beginning welders implies VR welding training can effectively aid in developing complex welding skills. We recommend that future research investigate the effectiveness of parameter cues and total cost-savings of integrated VR technology into welding training methods.

Introduction

Traditional Welding Training

Welding is considered a highly valued skill, requiring advanced psychomotor dexterity, cognitive capacity, and kinesthetic proficiency (Ref. 1). Not only does this job require great skill, it also demands that welders perform their job in precarious and difficult environments, as it remains a great necessity to overall infrastructure and manufacturing process chains (Ref. 2). In the past, these skills have been taught and developed through traditional welding training, comprised of repetitious and secluded training environments (Ref. 1). Unfortunately, traditional welding training is often costly and time-intensive (Ref. 3), two characteristics that threaten the welding industry as there exists a projected welder deficit of roughly 366,000 welders by 2026 (Ref. 4). As the need for adeptly trained welders increases, training will need to pivot to a more cost and time efficient model while still providing meaningful learning to these welders.

Throughout welding training, various factors affect a welders' ability to develop proper welding skills including individual backgrounds/abilities, cognitive capacity, and psychomotor dexterity (Ref. 5). There also exist many weld processes, as well as different metals, electrodes, and wires to utilize while welding. Traditional welding training can be intimidating, and understandably so as the welder manages flammable gases, sparks, and burning metal throughout the fabrication process (Ref. 4). Events like these can distract from learning the complex parameters required to perform high-quality welds. Five welding parameters are used as quality guides by welders to assess the durability and strength, as well as aesthetics of a weld. The five parameters include 1) Travel speed, 2) Travel angle, 3) Work angle, 4) Contact-to-workpiece-distance and 5) Position or "aim". Travel speed is the term used to describe how quickly the welder moves their weld gun (or electrode) across their metal workpiece. A very specific speed is required when welding: with a travel speed too fast, the metal will not fuse, but with a travel speed too slow, the metal will likely melt or distort (Ref. 4). Travel angle represents the angle in which a welder positions their weld gun (or electrode) on the horizontal plane, while Work angle represents where the weld gun is positioned on the vertical plane. Different types and positions of welds require very specific angles to ensure stability and thorough penetration (Ref. 4). Contact-to-workpiece-distance (CWTD) is understood as the distance between the tip of the weld gun and the metal. Welders must maintain proper CTWD by hovering their weld gun a distinct distance above the metal to perform quality welds. The last weld parameter, Position, is understood as the location in which a welder aims their weld gun. To ensure accuracy and complete joining, positioning and proper aim are essential (Ref. 4).

All these components of welding, along with learning the ins and outs of machine settings and equipment setup, are crucial when learning this fabrication skill (Ref. 2, 6). Considering where improvements can be made within the welding training sector, we turn to technology. Advanced technology offers a solution with benefits consisting of cutting consumable costs, lessening emission pollution, increasing accessibility, and decreasing training time, all while still providing effective learning opportunities for welders of all skill levels (Ref. 3). Computer-based audio assisted and virtual reality (CBAA and VR, respectively) technologies have recently been developed to provide personalized welding training, though their full potential is yet to be fully investigated (Ref. 7-9). CBAA welding training technologies involve real-life training methods supplemented with audial coaching and cues from CBAA systems that utilize cameras and sensors. Similarly, VR employs cues, however the training takes place in a 100% virtual environment. This paper will focus specifically on the VR welding training technology.

Virtual Reality Welding Training

VR technology, an advanced modern resource, is now commonly integrated into training throughout several skills-based professions. VR technology is used in training methods for industries such as aviation, surgery, engineering, construction, and countless more (Ref. 3, 10). VR technology allows for computer-generated simulations to create a virtual environment in which users experience and conduct various training tasks. Over the course of many years, simulations have become more advanced than researchers had initially imagined (Ref. 11, 12). VR training simulations are now customizable in that performance and grading parameter settings, physical environment, and user capacity can all be modified to personal or professional preference (Ref. 5). More specifically, VR welding training simulations have seen great benefits to training beginning welders (Ref. 13). Users are immersed into a virtual welding environment through use of oculus headsets, real time audio generation, and three-dimensional displays of the weld pool, metal workpiece, and weld gun (Ref. 14). While offering exposure to advanced technology and unique training methods, VR technology also yields several added benefits, four of which will be considered in this paper.

One primary benefit to integrating VR technology into a welding training program is the provision of a safe learning environment for beginning welders (Ref.3). Learners that participate in traditional welding training are exposed to sparks, burning gas, metal fumes, and ultraviolet radiation (Ref. 8). Many of these factors are concerning to inexperienced welders (Ref. 4). During VR training, all these events are simulated to the user virtually, rendering them safe from common dangers of traditional welding training (Ref. 3). As VR offers an environment that is both safe and authentic to users, it is an ideal training platform for dangerous activities like welding training (Ref. 15). Not only does the virtual environment protect users from welding hazards, but it aids in maintaining anxiety levels for beginning welders as well (Ref. 13). Being that welding is a task demanding advanced focus and skill, increased levels of anxiety are likely to affect weld quality and job performance (Ref. 13). Utilizing VR weld process training revealed that anxiety levels directly affected ability of welders to perform welds that pass visual inspections. Removing stressors commonly found in traditional welding training equip VR training with the advantage of a less stressful learning environment, allowing for better concentration on welding skill development (Ref. 13).

In addition to providing a safer alternative to its traditional counterpart, VR welding training has proven to be a more time and cost-efficient option for training beginning welders (Ref. 3, 16). VR welding simulators, such as the Lincoln Electric VRTEX 360, include software systems that afford straightforward, realistic set up tasks

(Ref. 17). Traditional welding booths require users to initiate and prepare various gas cylinders, welding tools, welding machines and gun attachments, and many other ancillary tasks. The VRTEX 360 allows users to complete these actions within the virtual environment at a more efficient rate. VR welding training also allows for multi-user access, meaning multiple users may train on the machine at the same time using dual VR welding stations. Whitney and Stephens (Ref. 3) found that this decrease in setup and breakdown time led to shorter required training times. They found that groups trained using VR training methods required two to three hours less total training time than those trained using traditional welding training methods. With less training time spent carrying out setup and breakdown tasks, more time can be devoted to increasing beginning learners' weld skill acquisition through more experience.

One study (Ref. 3) was able to measure the dollar amount of materials consumed during VR welding training and compare it to the actual amount of materials used in traditional training. The study found that the VR training required 33% less energy than the traditional welding training, while also maintaining a high qualification rate for all weld types. Another study (Ref. 6) measured the cost of materials consumed by a group of welders trained using 50% VR and 50% traditional training and compared it to a group using 100% traditional training. It was observed that the group receiving both VR and traditional training consumed significantly less materials (flat plates, groove plates, and electrodes) than the traditional training group. Total savings amounted to $243.68 per student as a result of integrating VR welding training (Ref. 6). By consuming less materials, decreasing required training time, and allowing for multi-user training, VR proves to be a practical asset within welding training settings.

The final and arguably the most important benefit of integrating VR technology into welding training is that it serves as a remarkable tool for the provision of meaningful experiential learning (Ref. 18, 19). Administering meaningful learning is especially important for beginning learners in that it facilitates knowledge creation and retention (Ref. 19). As users train in the virtual environment, they receive personalized feedback after every weld pass in the form of numerical weld and weld parameter grades. The VRTEX 360 tracks users' performance as they weld, scoring their ability to maintain acceptable welding techniques. This allows users to improve their welding techniques (work angle, travel angle, CTWD, travel speed, and position) while also receiving direct instruction from teachers observing the welders via external monitors. Cheater lenses are also available for use in VR welding training which allow for an enhanced view of the weld process for the user, another aspect of personalized feedback that VR welding simulators offer. One study (Ref. 18) identified an improvement in both engagement and metacognition of beginning welders upon completion of VR welding training in which they received personalized feedback. More recently, a study (Ref. 13) observed an increase in welder dexterity with the use of instant and accurate feedback from VR welding simulation training. The study also observed a faster rate of weld replication by using VR welding training. By allowing faster replication rates, learners receive more welding practice, feedback personalized to their welding style, direct instruction from the welding instructor, and thus in-depth experiential learning.

Amidst all these benefits, there also exist perceived drawbacks. One seemingly daunting hindrance to incorporate VR technology into welding training is the high initial associated cost. However, in most cases the initial cost of the training system can be partially or completely funded by green initiative and STEM grants for organizations and educational institutions (Ref. 3). Further, the cost savings the system would accumulate, depending on use, will ultimately match and exceed the initial cost of the technology implementation. Another perceived drawback is the classroom/laboratory management associated with the VR technology. Set up and management of the VR welding training equipment is relatively simple and minimal. The space required for a virtual welding machine and welding dock is up to 10ft. by 4ft., taking up minimal space in the classroom or lab. The headset, weld gun, coupons, and other attachments are all afforded storing compartments on the welding machine, therefore presenting no further issue than a traditional welding training station. The accessibility of the VR welding training systems can be 100% limited by the instructor via password protection or left available for students who wish to practice outside of lab hours. Utilizing VR welding training systems can offer an advanced, personalized form of welding training, though the effectiveness of the training method has yet to be fully identified (Ref. 5).

Theoretical Framework

The Ausubel's assimilation theory was used to guide our study in that the main interest is to provide beginning welders with meaningful learning via virtual weld process training (Ref. 20). In educational settings, the assimilation theory states that repetitious learning, in this case traditional welding training, is less effective than meaningful learning, specifically in aiding students to develop their metacognition and self-regulated learning (Ref. 20). Repetitious learning is understood as a method for learning that involves initial task instruction, followed by the completion of redundant training tasks, such as burning welding electrodes in a traditional welding training. Simply, Ausubel explains that repetitious learning alone is not enough to establish cognitive learning and thus retention of skills. The more effective meaningful learning is achieved by employing three main variables: 1) an appropriate level of inclusion of relevant concepts to the learning tasks; 2) clear stability and cohesivity of these concepts; and 3) distinguishability of these concepts from the learning task. In this study virtual welding training technology and researchers will provide meaningful learning by employing visual/audial cues and ample amounts of training time, thus allowing for the development of key weld performance skills among beginning welders. This method of practice will reflect a new training style in that beginning welders will receive personalized feedback from both the VRTEX 360 welding simulator, providing instantaneous grades, and the welding instructor, as they monitor the participants' welding performance progress. This training method benefits learners by expediting and enhancing their skill acquisition, allowing them to adjust their performance according to the various feedback they receive and therefore experiencing meaningful learning situations.

This framework is also supported by the peer learning theory being as the beginning welders involved in this study are encouraged to work in small teams on academic tasks to develop collective welding knowledge and performance skills (Ref. 21). Peer learning, specifically cooperative learning, benefits learners by enriching their educational experience with the positive use of differences between individuals. Cooperative learning occurs when learners, working in small teams, share the responsibilities of academic tasks and perform their tasks using cooperative/structured methods guided by an instructor (Ref. 21). Peer learning can be categorized into three different methods: peer tutoring, cooperative learning, and peer collaboration. When peer tutoring is used, the equality and mutuality between learners and instructors is low and the degree of structure is high, meaning the instructor is typically in control for the entire lesson and learners are not required to interact much. Peer collaboration is different in that the equality between learners and instructors is much higher, and the degrees of mutuality and structure are variable. By using peer collaboration, students share responsibilities and collaborate closely together, but the structure and level of interaction vary depending on the lesson and the individual learners' behaviors (Ref. 21). Lastly, cooperative learning ensures that the equality between students and instructor is high due to mutual and shared responsibilities. Mutuality between students is often moderate to high, depending on the level of cooperation required by the lesson, and can therefore fluctuate. The degree of structure when using cooperative learning is high as academic tasks, materials, and participation levels are all designed and reinforced by the instructor. When students are required to work in well-structured small teams to complete academic tasks with shared responsibilities, they perceive high levels of equality and mutually engage with each other throughout the lesson. Table 4.1 illustrates the three methods of peer learning and their respective levels of equality (between learner and instructor), mutuality (between learners), and structuring (of the lesson).

In this study, cooperative peer learning will be achieved by involving beginning welders, thus maintaining a high level of equality among participants. The level of mutuality in this study framework will be moderate to high as participants are expected to perform academic tasks individually, however, they are systematically planned in rotating sequences and will be performing the tasks together in the lab. The degree of structuring throughout this study is relatively high, having participants undergo systematic VR welding training protocol under the support and guidance of a researcher. Incorporating all these factors into the framework of this study will allow for the participants to experience advanced meaningful through the use of personalized feedback, and peer learning through mutual peer interactions in the VR welding laboratory.

Purpose and Objectives

This descriptive study is a part of a larger quasi-experimental study, and it aims to assess the effectiveness of VR welding training methods by comparing weld scores following each round of training. The secondary purpose of this descriptive study is to compare participants' live weld scores to their virtual weld scores. Live welds are performed using the traditional live welding training method and graded by an American Welding Society (AWS) Certified Welding Inspector (CWI). VR welds are performed using the VR welding training protocol established in this paper and graded by the VRTEX 360 welding simulator. The purpose for this study is to compare participants' weld scores produced using different welding training methods, identifying any statistical significance between the two. The objectives guiding this investigation are:

1. Collect mean scores for participants' virtual welds performed during the VR welding training session
2. Collect mean scores for participants' live welds performed during the traditional live welding training session
3. Compare the mean scores for participants' welds and identify any significant differences
4. Compare the live and virtual weld mean scores of all three sequence groups to determine if a significant difference exists

Methods and Procedures

This specific manuscript is a descriptive study, enveloped within a larger, randomized quasi-experimental research design. This study was conducted during a four-week timespan and replicated three times. Undergraduate students enrolled in the Introduction to Agricultural Engineering (AG 2373) course at Texas State University during the Spring ’21 (split into four total lab sections), Fall ’21 (three lab sections), and Spring ’22 (three lab sections) semesters at Texas State University served as our participants. Initially, all participants were asked to complete a paper-based demographics survey adapted from Wells and Miller (Ref. 5) that included questions regarding age, gender, dominant hand use for both general activities and welding activities, prior welding or VR experience, and other general demographic information. Following completion of the demographics survey, participants were randomly assigned to one of three sequence groups. Due to the course schedule and randomization, 35 participants were assigned to Sequence Group One, 30 participants to Sequence Group Two, and 28 participants to Sequence Group Three. Sequence groups schedules are presented in Table 4.2.

Participants then underwent one VR welding training session, audio assisted welding training, and live instruction welding training during the first three weeks in which they performed single pass 2F fillet welds on ¼” mild steel, using the GMAW process in the virtual environment. During the fourth week, participants underwent one traditional live welding training session in which they performed single pass 2F fillet welds on ¼” mild steel, using the GMAW process. Again, the sequence group schedule is presented in Table 2.

Virtual Welding Training

The VR welding training session protocol developed for this study aimed to utilize the virtual welding parameter cues offered by the VRTEX 360 without overwhelming the participants, therefore the protocol employs one cue per weld, as opposed to multiple cues at once. To begin the VR weld process training, a 10-minute script-supported introduction to the Lincoln Electric VRTEX 360 virtual welding simulator was given to participants by the researcher. The researcher explained the main components of the VRTEX 360 (oculus headset, welding gun, score screen, virtual weld coupon, and weld machine), how to set up the machine (selecting proper polarity, gas flow rate, wire-feed speed, and voltage), how to read and understand the visual/audial cues, and lastly how to perform welds in the VR environment. The researcher then demonstrated how to use the VRTEX 360 with practice weld passes. Participants were then provided paper-based score sheets to record their five parameter and overall weld scores assigned by the VRTEX 360 for each of their weld passes. For the VR welding training session, participants were required to complete three rounds of the training protocol established for this study. One round encompasses five total weld passes. The first four weld passes are practice runs, each performed with different parameter cue assistance. The last weld pass is the test run, performed without cue assistance. Practice Weld One is performed using the Travel Speed cue, Practice Weld Two using the Position cue, Practice Weld Three using the Travel/Work Angle cue, and Practice Weld Four using the CTWD cue. The final Test Weld is performed without cue assistance, mimicking live welding. Table 4.3 displays the training protocol developed for the virtual welding training session. All virtual welding training sessions were scheduled to last the entire duration of their lab period, approximately one hour and 40 minutes. However, some participant groups in the studies completed the training protocol early, though this was not determined as a limitation to the virtual training.

Virtual Parameter Cues

The visual and audial virtual parameter cues utilized in this research manifest in the virtual welding environment as gauges or icons, located at the tip of the user's weld gun. The Travel Speed cue measures the speed at which a user moves their weld gun across their workpiece, presenting as an arrow gauge. If the user's travel speed is too slow, the cue's arrow slides into the yellow or red zones, and if proper travel speed is maintained, the cue's arrow remains in the green zone. The Travel/Work Angle cue is a combined cue that measures the angles in which a user holds their weld gun. Presenting as a target that moves as users adjust their horizontal (travel) and vertical (work) angles, the cue is meant to be positioned directly in the crosshairs to maintain proper weld gun angles throughout the weld process. The Position/Aim cue is a colored aim line, indicating the exact aim of the weld gun. The goal of a 2F filet weld is to fuse two pieces of metal together, therefore aiming directly at the joint is integral. A user maintaining proper aim at the joint of the weld will see a green aim line. If the user's aim drifts upward or downward, the cue line becomes yellow or red, indicating the need to reposition weld gun aim. Finally, the CTWD cue appears as a colored arrow that hovers above a barrier symbol. A user that holds their weld gun too close to the workpiece (causing weld puddle spatter) will see the arrow become red, directing the user to move farther away. A user that holds their weld gun too far from the workpiece (causing a disruption in the arc) will see the arrow become red, directing the user to move closer to the workpiece. CTWD is another elemental factor of welding as proper CTWD ensures effective weld penetration.

Virtual Weld Scoring

In this research study, the parameter scores and overall weld scores for the virtual welds were determined by the VRTEX 360 virtual reality welding training simulator. The VRTEX 360 provides scores on a 100-point scale for each of the five welding parameters following the weld pass. Then the VRTEX 360 averages the five welding parameter scores to calculate an overall score for the weld pass. All weld scores are displayed on the score screen of the VRTEX 360. The participants were instructed to grade their weld on the VRTEX 360 score screen after the completion of their weld pass by pressing the "End Pass" button, prompting the system to grade the weld based on the five parameters previously stated. Following the completion of Round One, participants then rotated using the VRTEX 360 with their peers to complete three rounds of the virtual welding training protocol.

Traditional Live Welding Training

As previously mentioned, during the fourth week of this research study participants underwent a traditional live welding training session. This live welding training took place in the Texas State Agricultural Science welding laboratory, simulating a traditional welding training environment equipped with individual welding machines and booths. During this training session, participants were supervised by the researcher and an AWS CWI. Participants performed single pass 2F fillet welds on ¼" mild steel coupons using the GMAW process. At the conclusion of the traditional live welding training session, participants were instructed to submit their best weld to the CWI to be assessed and graded on a 100-point scale. All participants were given the entire duration of their lab period (one hour and 40-minutes) to complete the traditional live welding training session.

Data Collection and Analysis

Data collected from the virtual welding training sessions include mean scores for all participants' parameter and overall weld scores from virtual welds performed with and without cue assistance. Scores for welds using the different parameter cue assistance were compared and analyzed for significant results. Furthermore, overall weld scores for virtual welds performed during Rounds One, Two, and Three of the virtual welding training session were compared and analyzed for significant results. Data collected from the traditional welding training session are the mean weld scores for all participants' live welds performed in a traditional welding setting, as determined by the CWI. The mean scores for virtual welds were compared and analyzed against the mean scores for live welds in order to identify significant results.

Results

A demographic survey was distributed to all participants (N = 108) prior to welding training. A select few (n = 4) participants' information was excluded as they failed to complete the entire welding training sequence. The demographic information determined that there was a similar ratio of female and male participants (f = 51, 53 respectively). The age of our participants ranged from 18 to 23+ and a majority of them were sophomores and juniors (f = 33, 37). Roughly 65% of participants had no prior welding experience, and 95% of the participants reported having no welding simulator or simulation experience. Additional demographic information collected is displayed in Table 4.4.

Using the VR welding simulator, all participants' (*N* = 104) average mean score for the first test run was 62.10 (*SD* = 27.10). The mean score for participants' second test run was 84.03 (*SD* = 7.30), and the mean score for participants' third VR test run was 84.41 (*SD* = 8.16). Using the traditional live welding training method, participants' live welds produced during Week Four was 83.40 (*SD* = 5.48). These mean score results are presented in Table 4.5.

As mentioned previously, all participants completed the virtual welding training in different sequence groups, therefore data from individual sequence groups was analyzed. Table 4.6 displays the mean weld scores for Sequence Group One. Participants in this sequence group produced a mean score of 76.83 (*SD* = 10.13) for their first VR test weld, 80.77 (*SD* = 8.93) for their second VR test weld, and 83.26 (*SD* = 6.56) for their final VR test weld. Table 4.7 displays the mean weld scores for Sequence Group Two. Participants in this sequence group produced a mean score of 81.93 (*SD* = 7.49) for their first VR test weld, 84.23 (*SD* = 5.28) for their second VR test weld, and 85.27 (*SD* = 4.74) for their final VR test weld. Table 4.8 presents the mean weld scores for Sequence Group Three. Sequence Group Three participants had received the most welding training prior to their VR training and performed a mean weld score of 85.14 (*SD* = 5.89) for their first VR test weld, 86.79 (*SD* = 5.30) for their second VR test weld, and 85.27 (*SD* = 4.74) for their final VR test weld.

Discussion

Results from this research indicate that with each round of VR welding training, participants' test weld scores continuously increased. By the final round of VR training, participants were consistently scoring 80% and higher, comparable to the previously established mean pass rate of <40% for welders who received traditional welding training (Ref. 6). This enhanced performance of beginning welders implies VR welding training can aid in developing complex welding skills. Considering our Skills Assimilation theoretical framework, we propose welding performance proficiency was successfully acquired through VR welding training and has the potential to results in faster skill acquisition than traditional welding training (see Figure 2).

Furthermore, mean scores for test welds completed on the VRTEX 360 were comparable to the participants' mean score for test welds completed using the live weld process and graded by a CWI. This suggests the factory settings of the VRTEX 360 used in the study align sharply with the grading parameters for AWS CWI's. Anecdotally, participants in this study, though beginning welders, were comfortable around the VR welding equipment and expressed lower levels of anxiety and apprehension compared to entering the live welding lab. Approachability of VR welding training could play a key benefit in future integration.

Data collected from the individual sequence group trainings show that, on average, the sequence groups with more welding training performed better. Sequence Group One, who had no prior welding training, performed VR test welds ranging from 76.83 to 83.26, while Sequence Group Two, who had one week of prior welding training, performed VR test welds ranging from 81.93 to 85.27. By the time Sequence Group

Three underwent the VR weld training, they had two weeks of welding training, resulting in their VR test weld scores ranging from 84.86 to 86.79. Our results reveal that Sequence Group Three outperformed the other groups, suggesting the increased amount of welding training benefited their welding performance abilities.

Future investigations of VR welding training should utilize the virtual and audial parameter cues to assist learners in understanding complex welding concepts. It is recommended to extend the length of virtual training sessions to allow learners ample time to familiarize themselves with the virtual environment, as well as ample practice time. It is also recommended that a larger sample population be used.

Research involving VR welding training should also make a point to track the amounts of metal, gas, wire, and electricity "used" within the virtual welding environment. Such information would express cost savings resulting from VR technology integration, which has yet to be fully understood. Instructors implementing VR into their welding training can expose apprehensive beginning students to the virtual environment before the dangerous live welding lab. Instructors can also use VR welding training technology to allow experienced welders to fine-tune their existing welding skills.

Finally, it is recommended that future research involving VR welding training collect live weld performances and scores following each training. This will allow for a more accurate comparison of weld performances and help to understand if virtual weld training is actually reflective of live welding.

Conclusions

1.) Results from this study show that as beginning welders receive more virtual training, their weld scores continue to increase. For each sequence group, as they progressed in the VR welding training, their weld performance improved. This indicates that the virtual welding simulator helped to promote proper welding skill acquisition.

2.) Participants in this study consistently scored an average of about 80 and higher for their virtual welds. These scores are relatively high compared to traditional welding training methods, suggesting that the use of VR technology in welding training proves advantageous in a number of ways. The VR training provided high-quality, meaningful learning at an expedited rate, yielding better results than similar traditional trainings.

3.) As the participants received more welding training, their virtual weld scores continued to increase, and their standard deviations tightened. Sequence Group One which performed their virtual welds with the least amount of training time, was outperformed by Sequence Group Two. Consecutively, Sequence Group Two was outperformed by Sequence Group Three which performed their virtual welds with the largest amount of training time. It is safe to conclude that an increased amount of training time positively affects the ability to perform high-quality virtual welds.

Tables

Table 4.1 Characteristics of Three Peer Learning Methods

Peer Learning Characteristic	Three Methods of Peer Learning Peer Tutoring	Peer Collaboration	Cooperative Learning
Equality	Low: Directional flow from instructor to learner, instructor controls the information and agenda.	High: Bidirectional flow between instructor and learners, mutual shared responsibilities between learners.	High: Bidirectional flow between instructor and learners, mutual shared responsibilities.
Mutuality	Low–Moderate: Favored by peer relations but is variable depending on instructor's qualities and learner's receptivity.	Variable: Usually high with learners working together on the same task but can vary depending on psycho-social factors.	Moderate–High: Varies depending on cooperative methods and can be reinforced with systematic planned sequence.
Degree of Structuring	High: Structured academic task and material.	Variable: Depends on the situations and the organization endorsed by the learners.	High: Academic task, material, and participation structured by instructor.

Table 4.2 Weld Process Training Sequences for the Four-Week Welding Training

Sequence Group	Week One Weld Process Training	Week Two Weld Process Training	Week Three Weld Process Training	Week Four Weld Process Training
Sequence Group 1	Virtual Reality (VR)	CBAA	Live	Live Weld Test
Sequence Group 2	Computer-Based Audio Assisted (CBAA)	Live	VR	Live Weld Test
Sequence Group 3	Live	VR	CBAA	Live Weld Test

Table 4.3 Protocol for One Round of VRTEX 360 Weld Process Training

Weld Pass	Visual/Audial Cue Employed
Practice Run 1	Travel Speed Cue
Practice Run 2	Position/Aim Cue
Practice Run 3	Travel/Work Angle Cue
Practice Run 4	Contact To Workpiece Distance Cue
Test Run	None

Table 4.4 Participant Demographics (N = 108)

Item	f	%
Gender		
Female	53	49.1
Male	51	47.2
Other	2	1.9
Chose Not to Answer	2	1.9
Age		
18	10	9.3
19	23	21.3
20	19	17.6
21	18	16.7
22	16	14.8
23+	20	18.5
Chose Not to Answer	2	1.9
Dominant hand for most tasks		
Right hand	92	85.2
Left hand	14	13.0
Chose Not to Answer	2	1.9
Dominant hand for welding		
Right hand	96	88.9
Left hand	10	9.3
Chose Not to Answer	2	1.9
Academic grade level		
Freshman	16	14.8
Sophomore	33	30.6
Junior	37	34.3
Senior	20	18.5
Chose Not to Answer	2	1.9
Previous welding experience		
No	71	65.7
Yes	35	32.4
Chose Not to Answer	2	1.9
If you have welded before, which of the following processes have you performed?		
Shielded metal arc welding (SMAW; “Stick welding”)	29	26.9
Gas metal arc welding (GMAW; “MIG”; “wire welding”)	19	17.6
Oxy-fuel welding (OFW)	11	10.2
Flux-cored arc welding (FCAW)	4	3.7
Gas tungsten arc welding (GTAW)	4	3.7
Submerged arc welding (SAW)	1	0.9
Previous welding simulation / simulator system use		
Yes	3	2.8
No	103	95.4

Chose Not to Answer	2	1.9
Achievement of a welding certification		
Yes	2	1.9
No	104	96.3
Chose Not to Answer	2	1.9

Table 4.5 VRTEX 360 Mean Scores for Test Runs and Certified Weld Inspector (CWI) Mean Score for Live Welds (N = 104)

Weld Scored	Mean Score	*SD*	*t*	*p*
Round 1 Test Run	62.10	27.10	-8.02	<0.00
Round 2 Test Run	84.03	7.30	0.88	0.38
Round 3 Test Run	84.41	8.16	1.25	0.21
Live Weld (CWI Grade)	83.40	5.48		

Table 4.6 Sequence Group One VRTEX 360 Mean Scores for Test Runs and Certified Weld Inspector (CWI) Mean Score for Live Welds (n = 35)

Weld Scored	Mean Score	SD	t	p
Round 1 Test Run	76.83	10.13	-3.09	<0.05
Round 2 Test Run	80.77	8.93	-0.89	0.38
Round 3 Test Run	83.26	6.56	1.04	0.31
Live Weld (CWI Grade)	82.11	7.79		

Table 4.7 Sequence Group Two VRTEX 360 Mean Scores for Test Runs and Certified Weld Inspector (CWI) Mean Score for Live Welds (*n* = 30)

Weld Scored	Mean Score	*SD*	*t*	*p*
Round 1 Test Run	81.93	7.49	-2.00	0.06
Round 2 Test Run	84.23	5.28	-0.45	0.65
Round 3 Test Run	85.27	4.74	0.69	0.50
Live Weld (CWI Grade)	84.67	3.80		

Table 4.8 Sequence Group Three VRTEX 360 Mean Scores for Test Runs and Certified Weld Inspector (CWI) Mean Score for Live Welds (*n* = 28)

Weld Scored	Mean Score	*SD*	*t*	*p*
Round 1 Test Run	85.14	5.89	0.96	0.34
Round 2 Test Run	86.79	5.30	2.71	<0.05
Round 3 Test Run	84.86	12.48	0.33	0.74
Live Weld (CWI Grade)	84.07	3.71		

Figures

Figure 4.1. Score screen of the Lincoln Electric VRTEX 360 Virtual Welding Simulator

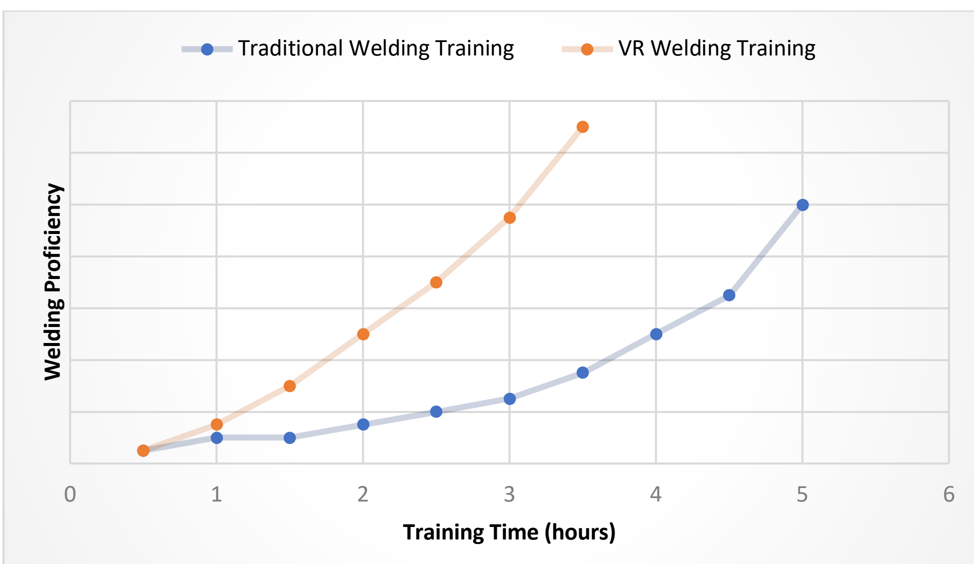

Figure 4.2. Projected proficiency development of trainees through VR and traditional welding training

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V. ASSESSING THE EFFECTS OF VIRTUAL CUE IMPLEMENTATION IN VIRTUAL REALITY WELDING TRAINING

A paper prepared for submission to the American Welding Society *Welding Journal.*

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Abstract

Incorporating virtual reality (VR) technology into educational and training environments has proved effective, specifically because it allows training to remain safe, efficient, and meaningful. Welding training is no exception, with research exhibiting benefits such as decreased welder anxiety, increased cost- and time-efficiency, reduction in material usage, and advanced levels of skill acquisition. As the country faces an encroaching welder deficit across industries, the demand for highly skilled welders will continue to rise. Our research aims to provide meaningful and experiential learning to beginner welders, equipping them with entry-level welding skills to enter the welding industry while simultaneously identifying their professional development needs by employing various parameter cues using the Lincoln Electric VRTEX 360 Welding Simulator. This four-week study was completed at Texas State University and replicated three times. Undergraduate (N=108) students enrolled in Introduction to Agricultural Engineering,

[3] Though this manuscript was co-authored, more than 51% of the work was completed by Brittney H. Heibel

randomized into one of three sequence training groups, served as our participants. All participants performed single-pass 2F welds using the Gas Metal Arc Welding process. On average, results indicate the most difficult parameter to master was Travel Speed, while the most straightforward parameter was Contact-to-Workpiece-Distance. Assessing the three sequence training groups individually, we find that the Travel Speed parameter is consistently the most difficult to master, however, as participant welding experience increased, so did their welding parameter scores. Considering this study's quasi-experimental design, recommendations for future research include investigating VR weld training utilizing more complex weld configurations and processes, larger sample sizes, beginning welder sample groups, and varied training durations.

Introduction

Welding is a highly valued skill that requires advanced psychomotor dexterity, cognitive capacity, and kinesthetic proficiency. These skills have traditionally been developed through standardized welding training via agricultural mechanics courses, vocational/trade schools, and industry trainings (Ref. 1). Welding training is typically comprised of safety lessons, machine and lab setup, equipment and materials knowledge, weld process techniques, and personal welding practice using the various processes and materials. Countless factors can affect a welders' ability to develop these complex skills like individual backgrounds or previously acquired knowledge and habits, making training a lengthy ordeal at times (Ref. 2). These time-consuming trainings are also quite costly, due to the high material usage (e.g., electrodes, welding wire, steel, natural gas) and equipment requirements (e.g., torch tips, welding machines, grinders). These inherent issues, coupled with the 366,000 predicted welder deficit facing the industry by 2026, underpin the need for a more efficient method of welding training (Ref. 3).

A Technical Solution

A key solution for the welding industry has been realized in modern technology, specifically virtual reality (VR). Incorporating VR simulation technology in educational and career and technical education (CTE) environments, including various welding studies, has shown to be effective, specifically because it allows training of any kind to remain safe, efficient, and meaningful (Ref. 4-6). Effective VR systems revolve around three key components: (1) user immersion, (2) ability to navigate, and (3) ability to manipulate (Ref. 7). VR's exceptional interactivity has led to its heavy use across diverse educational settings (Ref. 4). This technology is used in training methods for industries such as aviation, surgery, engineering, construction, and countless more (Ref. 6, 8). VR technology allows for computer-generated simulations to create virtual environments in which users experience and conduct various training tasks. Over the course of many years, simulations have become more advanced than researchers had initially imagined, resulting in the integration of VR technology into welding process trainings (Ref. 7, 9).

VR training simulations are customizable in that performance settings, grading parameter settings, physical environment, and user capacity can all be modified to personal or professional preference (Ref. 2). Integration of VR welding training simulations has seen great benefits for beginning welders (Ref. 10). Within these VR welding training simulations, users are immersed into a virtual welding environment through use of oculus headsets, real time audio generation, and 3-dimensional displays of the weld pool, metal workpiece, and weld gun (Ref. 11). While offering exposure to advanced technology and unique training methods, VR technology also yields several added benefits, four of which will be considered in this paper.

Key Benefits to Virtual Reality Integration

One primary benefit to integrating VR technology into a welding training program is the provision of a safe learning environment for beginning welders (Ref. 6). Learners that participate in traditional welding training are exposed to sparks, burning gas, metal fumes, and ultraviolet radiation. Many of these factors are concerning to inexperienced welders (Ref. 3). During VR training, all these events are simulated to the user virtually, rendering them safe from common dangers of traditional welding training (Ref. 6). As VR offers an environment that is both safe and authentic to users, it is an ideal training platform for dangerous activities like welding training (Ref. 12). Not only does the virtual environment protect users from welding hazards, but it aids in maintaining anxiety levels for beginning welders as well. Being that welding is a task demanding advanced focus and skill, increased levels of anxiety are incredibly likely to affect weld quality and job performance (Ref. 13). A study utilizing VR weld process training revealed that anxiety levels directly affected the ability of welders to perform welds that pass visual inspections (Ref. 13). Removing stressors commonly found in traditional welding training equip VR training with the advantage of a less stressful learning environment, allowing for better concentration on welding skill development.

In addition to providing a safer alternative to its traditional counterpart, VR welding training has proven to be a more time and cost-efficient manner for training beginning welders (Ref. 6, 14). VR welding simulators, such as the Lincoln Electric VRTEX 360, include software systems that afford straightforward, realistic set up tasks for users (Ref. 15). Traditional welding booths require that users initiate and prepare various gas tanks, welding tools, welding machines, gun attachments, and complete many other ancillary tasks. The VRTEX 360 allows users to complete all these actions within the virtual environment at a more efficient rate. VR welding training also allows for multi-user access, meaning multiple users may train on the machine at the same time using dual VR welding stations. Recent research found that this decrease in setup and breakdown time led to shorter required training times as groups using VR welding training required 2-3 hours less training time than those using traditional welding training (Ref. 6). With less training time required for setup and breakdown tasks, paired with multi-user welding stations, more time can be devoted to increasing the learners' weld skill acquisition.

The third benefit realized in VR technology integration is that of material and cost savings. A study measuring the total amount and cost of materials "consumed" during a VR welding training compared the usage to that of a similar traditional welding training (Ref. 6). Results demonstrate that the VR welding training required 33% less electrical energy than the traditional welding training, while also maintaining a high qualification rate for all weld types. Another study measured the cost of materials consumed by a group of welders trained using 50% VR and 50% traditional training, then compared it to a group of welders using 100% traditional training (Ref. 16). Researchers reported the group receiving both VR and traditional training consumed significantly less materials (e.g., steel flat plates, steel groove plates, and welding electrodes) than the traditional training group. The study reported a substantial savings of $243.68 per student as a result of integrating VR welding training (Ref. 16). This significant reduction in training costs by means of material, energy, and equipment savings indicates that VR is a proven practical asset for welding training.

The final, and arguably most important, benefit of integrating VR technology into welding training is that it serves as a remarkable tool for the provision of meaningful experiential learning (Ref. 5, 17). Administering meaningful learning is especially important for beginning learners in that it facilitates knowledge creation and retention. Additionally, experiential learning provides abstract conceptualization, reflective observation, and active experimentation, resulting in more concrete educational experiences for beginning learners (Ref. 5). As users train in the virtual welding environment, they receive personalized feedback after every weld pass in the form of numerical parameter and overall weld scores. The VRTEX 360 tracks users' performance as they weld, scoring their ability to maintain acceptable welding techniques. This allows users to improve their welding parameter techniques (work angle, travel angle, contact tip-to-workpiece-distance (CTWD), travel speed, and position) while also receiving direct instruction from teachers who observe the users via external monitors. Cheater lenses are also available for use in VR welding training which allow for an enhanced view and understanding of the weld process. Research reported significant improvements in both user engagement in the lesson and metacognition of beginning welders upon completion of VR welding training in which they received personalized feedback (Ref. 17). More recent research observed an increase in welder dexterity with the use of instant and accurate feedback from VR welding simulation training (Ref. 10). The same research also observed a faster rate of weld replication by implementing VR welding training. These faster replication rates allow for more welding practice, as well as more feedback personalized to their welding style. This increased volume of training paired with direct instructor feedback provides meaningful, experiential learning that will positively influence learners' welding education and skill acquisition.

Theoretical Framework

The overarching framework of this study is guided largely by the skill acquisition theory. This theory explains that the development of skills occurs in three stages: declarative knowledge, procedural actions, and automaticity (Ref. 18). During the declarative stage, learners begin understanding the skills and steps required to complete a task, also called declarative knowledge (Ref. 2). Next, the learner transforms their declarative knowledge into procedural knowledge by applying their basic understanding of a concept into action. This is through means of practice, targeting increased accuracy and time efficiency. With adequate practice, the learner is guided into the automaticity stage. A learner has reached automaticity when they are able to alter their focus as they complete a task. These stages are present throughout all five levels of skill development which include beginning, advanced beginner, competence, proficiency, and expertise levels (Ref. 18). The goal of any effective training is to facilitate learners progressing from one level of skill to the next, in an efficient and meaningful manner. In this study, participants will enter the training as beginning welders and progress through the levels of skill development via virtual welding training.

Ausubel's assimilation theory also guided our study framework in that the main interest is to provide beginning welders with meaningful learning via weld process training. The assimilation theory explains that repetitious learning, for example traditional welding training, is less effective than meaningful learning in helping students develop their metacognition and self-regulated learning (Ref. 19). Simply, repetitious learning alone is not enough to establish cognitive learning and thus retention of skills (Ref. 19). Meaningful learning can be employed by providing three main variables: 1) an appropriate level of inclusiveness of relevant concepts to the task; 2) clear stability and cohesivity of concepts; and 3) distinguishability from the learning task. In this study, VR technology and training practices are utilized to enact meaningful learning. Meaningful learning is to be achieved by providing visual and audial cues within the virtual training environment, weld performance skill development, and sufficient skill practice time over the four-week span. This method of practice will reflect a new training style in that beginning welders will receive personalized feedback from both the VRTEX 360 welding simulator and the welding instructor. It will benefit learners by expediting and enhancing their skill acquisition, allowing them to adjust their performance according to the various feedback they receive and therefore experience meaningful learning situations.

Purpose and Objectives

This study aims to provide meaningful, experiential learning to beginning welders, equipping them with entry-level welding skills necessary to enter the welding industry. The purpose of the study is to identify the professional development needs of beginning welders by employing various parameter cues using the Lincoln Electric VRTEX 360 Welding Simulator. The VRTEX 360 measures welding skill performance by tracking five weld variables: 1) travel speed, 2) travel angle, 3) work angle, 4) contact tip-to-workpiece distance (CTWD), and 5) position. These scores are averaged to calculate the overall score of the weld (*VRTEX® 360® Single User Virtual Reality*

Welding Training Simulator on Pallet, 2021). Utilizing VR welding simulators, the main objectives of this study are to:

1. Identify participant travel speed scores with and without travel speed cue assistance
2. Identify participant position scores with and without position cue assistance
3. Identify participant travel angle scores with and without travel/work angle cue assistance
4. Identify participant work angle scores with and without travel/work angle cue assistance
5. Identify participant CTWD scores with and without CTWD cue assistance
6. Compare the parameter mean scores for the three sequence groups to determine if a significant difference exists

Methods and Procedures

Experimental Design

Our four-week descriptive study was conducted at Texas State University and replicated three times. Undergraduate students ($N = 108$) enrolled in the Introduction to Agricultural Engineering (AG 2373) course during the Spring '21, Fall '21, and Spring '22 semesters served as our participants. Upon approval from the Institutional Review Board, participants were asked to complete a paper-based demographics survey adapted from Wells and Miller (Ref. 2) including questions regarding age, gender, dominant hand use for both general activities and welding activities, and prior welding or VR experience. As this was a part of a larger study, a quasi-experimental design was applied in which participants were randomly assigned to one of three experimental sequence groups using a randomization formula in Excel. Each sequence group was then assigned a weld process training sequence to include VR, computer-based audio assisted (CBAA), and live weld process training (see Table 5.1). Due to the course schedule and randomization, 35 participants were assigned to Sequence Group One, 30 participants to Sequence Group Two, and 28 participants to Sequence Group Three.

Instrumentation

In order to achieve our research objectives, the VR welding training protocol developed for this study aimed to utilize the virtual welding parameter cues offered by the VRTEX 360 without overwhelming the participants. Therefore, the protocol employs one cue at a time, as opposed to multiple cues at once. The VR welding training took place in the Texas State Agricultural Mechanics' VR laboratory, outfitted with a dual-station VRTEX 360 VR welding simulator. To begin the VR welding training session, a 10-minute script-supported introduction to the VRTEX 360 was given by the researcher. The researcher explained the main components of the VRTEX 360 (oculus headset, welding gun, score screen, virtual weld coupon, and weld machine), how to set up the machine (selecting proper polarity, gas flow rate, wire-feed speed, and voltage), how to read and understand the visual/audial cues, and lastly how to perform welds in the VR environment. Following a brief virtual welding demonstration from the researcher, participants were then provided paper-based score sheets to collect their scores assigned by the VRTEX 360 for each of their weld passes.

For the VR welding training session, participants were required to complete three rounds of the training protocol established for this study. *One round* includes five total weld passes. The first four weld passes are practice runs, each performed with different parameter cue assistance. The last weld pass is the test run, performed without cue assistance. Practice Weld One is performed using the Travel Speed cue, Practice Weld Two using the Position cue, Practice Weld Three using the Travel/Work Angle cue, and Practice Weld Four using the CTWD cue. The final Test Weld is performed without cue assistance, mimicking live welding. Table 5.2 displays the training protocol developed for the virtual welding training session.

All virtual welding training sessions were scheduled to last the entire duration of the participants' lab period; approximately one hour and 40 minutes. However, some participant groups completed the training protocol 5-15 minutes early, though this was not determined as a limitation to the virtual training.

Virtual Parameter Cues

The visual and audial virtual parameter cues utilized in this research manifest in the virtual welding environment as gauges or icons, located at the tip of the user's weld gun. The Travel Speed cue measures the speed at which a user moves their weld gun across their workpiece, presenting as an arrow gauge. If the user's travel speed is too slow, the cue's arrow slides into the yellow or red zones, and if proper travel speed is maintained, the cue's arrow remains in the green zone. The Travel/Work Angle cue is a combined cue that measures the angles in which a user holds their weld gun. Presenting as a target that moves as users adjust their horizontal (travel) and vertical (work) angles, the cue is meant to be positioned directly in the crosshairs to maintain proper weld gun angles throughout the weld process. The Position/Aim cue is a colored aim line, indicating the exact aim of the weld gun. The goal of a 2F filet weld is to fuse two pieces of metal together, therefore aiming directly at the joint is integral. A user maintaining proper aim at the joint of the weld will see a green aim line. If the user's aim drifts upward or downward, the cue line becomes yellow or red, indicating the need to reposition weld gun aim. Finally, the CTWD cue appears as a colored arrow that hovers above a barrier symbol. A user that holds their weld gun too close to the workpiece (causing weld puddle spatter) will see the arrow become red, directing the user to move farther away. A user that holds their weld gun too far from the workpiece (causing a disruption in the arc) will see the arrow become red, directing the user to move closer to the workpiece. CTWD is another elemental factor of welding as proper CTWD ensures effective weld penetration. Parameter cues and their respective functions are displayed in Table 5.3. Visual representations of the parameter cues as they are displayed in the virtual welding environment of the VRTEX 360 are shown in Figure 1. All cues are displayed at the tip of the user's weld gun in the virtual environment.

Virtual Weld Scoring

In this study, the parameter scores and overall weld scores for the virtual welds were determined by the VRTEX 360 virtual reality welding training simulator. The VRTEX 360 provides scores on a 100-point scale for each of the five welding parameters following the weld pass. Then the VRTEX 360 averages the five welding parameter scores to calculate an overall score for the weld pass. All weld scores are displayed on the score screen of the VRTEX 360. Figure 2 displays the score screen of the VRTEX 360, the overall score seen to the left, the virtual weld in the center, and individual parameter scores to the right.

The participants were instructed to grade their weld on the VRTEX 360 score screen after the completion of their weld pass by pressing the "End Pass" button, prompting the system to grade the weld based on the five parameters previously stated. Participants then recorded their five parameter scores and their overall weld score for each of the five weld passes during Round 1, totaling 30 values per round. Following the completion of Round 1, participants then rotated using the VRTEX 360 with their peers to complete three total rounds of the virtual welding training protocol. Throughout the VR training session, participants were allowed and encouraged to observe each other, promoting the level of meaningful and peer learning in the training environment.

Results

Selected participant demographic data is displayed in Table 5.4 using frequencies and percentages of responses. A series of paired-samples t-tests were used to analyze mean parameter and overall weld scores for each round completed by study participants. Mean and overall weld scores for each sequence group were also analyzed and compared. This study collected demographic data from 108 participants, 53 (49.1%) of which were female, 51 (47.2%) were male, and 4 (3.8%) declined to answer or selected "other". Information regarding participants' prior VR and live welding experience are shown in Table 5.5. Most participants had never welded before (f = 71; 65.7%) and of the participants who had prior welding experience, the most common weld process used was SMAW (f = 29; 26.9%), followed by GMAW (f = 19; 17.6%). Only three (2.8%) participants had prior welding simulator experience, and only two (1.9%) participants possessed welding certifications.

Descriptive statistics of the parameter scores for participants (n = 103) during the VR welding training are presented in Table 5.6. Five participants did not fully complete the training; therefore their data was not included. Our results indicate that participants' parameter scores were higher when the virtual cues were off for all parameters but Travel Speed. All differences between parameter scores with and without cue assistance were statistically significant ($p < 0.05$).

As previously stated, the participants completed VR welding training by way of three different sequence groups. Sequence Group One's data are presented in Table 5.7. Participants from Sequence Group One appeared to struggle the most with the Travel Speed parameter, with a mean score of 79.34 with cue assistance, and a mean score of 78.94 without cue assistance. Sequence Group Two's data are presented in Table 5.8. Sequence Group Two participants, having one week worth of welding training at this point, struggled most with Travel Speed and Position, with a mean score of 72.58 and 80.61 without cue assistance, respectively. Sequence Group Three's data are presented in Table 5.9. This sequence group had received two weeks of welding training at this point. Participants in Sequence Group Three struggled the most with the Travel Speed parameter, with an increased mean score of 83.93 with cue assistance and 78.8 without cue assistance. Participants in Sequence Group 3 continually scored an average of 90 and higher for all other weld parameters, with and without cue assistance.

Conclusions and Discussion

The purpose of the study was to identify the professional development needs of beginning welders through use of VR welding training technology. Several conclusions can be drawn from the results of this study. First, it was observed that the virtual parameter cues implemented during the VR welding training provided personalized feedback to the beginning welders that allowed them faster weld skill acquisition. The framework of this experiment involved participants performing virtual welds while utilizing parameter cues, then progressing to performing the same virtual welds without parameter cues. Results of this training method show statistically significant (p <0.05) impacts on participants' pass rates for a single pass 2F weld using the GMAW process. These results indicate that throughout the welding training, procedural knowledge of weld skill performance was developed at a faster rate than previously established rates of traditional welding training. In previous research, beginning welders who received traditional welding training for 2F welds under Stone et al. (Ref. 20) scored a <40% mean pass rate following 6 hours of training while participants in this study scored a >68% mean pass rate for a similar amount of training time. Furthermore, a previous study by Byrd (Ref. 13) using VR welding training methods saw experienced welders maintain average scores in the 70s for selected weld types. Results indicate that through utilizing parameter cues within the VRTEX 360, beginning welders performed at a comparable level to experienced welders and thus saw an increase in weld skill performance as well as acquisition. Rooted in the skills acquisition theory, this 68% CWI inspection passing rate displays how participants in this study progressed from beginning to advanced beginner level welders. Realizing these implications, VR technology could play an integral role in the future training of welders to meet the growing industry demands.

It can also be concluded from these results that the Travel Speed parameter of the weld process is the most difficult for beginning welders to master. When the parameter scores for our participants were evaluated, all parameter scores were higher when the cues were not being utilized, except for Travel Speed. This could indicate that the participants were apt to develop the other four parameter skills throughout the VR training but continued to struggle with Travel Speed. In many cases, beginning welders can face nerves or anxiety during the welding process, even in virtual environments (Ref. 13). This often causes the welder to speed through the process, not taking the necessary time required to perform a high-quality, penetrating weld. Even if a welder has appropriate position, angles, and contact distance, if they are welding too fast or too slow, they will not produce a high-quality weld.

Another interesting finding within this study is that Sequence Group One, having no prior welding training, struggled the most with the Travel Speed weld parameter. This cue was engaged during the participants first weld passes in the training session, potentially justifying the low score as they adapt to the VR environment. Sequence Group Two, having one week of prior welding training, struggled with Travel Speed and Position weld parameters the most. Sequence Group Three appears to have struggled only with the Travel Speed weld parameter. The fact that all sequence groups were scoring the lowest on the Travel Speed parameter during their test welds indicates that the participants were retaining the most recently covered parameters. Participants were given the Travel Speed cue first, followed by the other three parameter cues, therefore we conclude that they may have lost focus on the Travel Speed parameter by the time they performed their test weld. Inversely, because the participants were receiving practice while performing these weld passes, as well as becoming more adapted to the VR environment, this could have a significant effect on their parameter and overall weld scores.

Recommendations

Considering this study's quasi-experimental design, recommendations for future research include studies investigating VR weld training utilizing various weld configurations and processes, larger sample sizes, and longer training durations. For this study, a basic 2F weld using the GMAW process was elected when considering simplicity and level of skill required in the Introduction to Agricultural Engineering course. It is recommended that further replication involving groups of beginning welders include VR training for more complex weld configurations including horizontal, vertical, and overhead positions, as well as different weld processes. Due to the limited number of participants in this study, it is recommended that this study be replicated involving a larger sample size. By including more participants, a greater understanding of parameter cues' effects on beginner welders may be realized. Additionally, as Wells and Miller (Ref. 2) identified effects of VR training on a group over the course of a one-hour training period, this study investigated the effects of VR training on a group over a more extended period. Therefore, it is recommended that future research explore the effects of VR training over longer durations to determine the impact of VR training in scenarios which better reflect professional training programs. Further research is required to understand effectiveness of alternative cue employment sequencing within VR weld training.

Welding instructors and educators that seek to incorporate VR into their weld process training programs should provide learners with adequate practice time utilizing one cue at a time. Results from analyzing the sequence group scores indicates that, when first introducing beginning welders to VR welding training, Travel Speed should be a key focus of training. Once they have gained some experience, the focus should shift to both Position and Angles of the weld gun. It is recommended that once learners have more experience, they should use the VR weld training to focus on perfecting their Travel

Speed and CTWD. It is also recommended that once learners are capable of consistently scoring 90 or higher for each parameter and weld scores, indicating they have reached automaticity regarding that cue, they should then move on to practicing with the next cue. Training with these structured, meaningful learning experiences will prepare beginning welders with the skill development required of potential future welders.

Tables

Table 5.1. Weld Process Training Sequences

Sequence Group	Weld Process Training for Week One	Weld Process Training for Week Two	Weld Process Training for Week Three
Sequence Group One	Virtual Reality (VR)	CBAA	Live
Sequence Group Two	Computer-Based Audio Assisted (CBAA)	Live	VR
Sequence Group Three	Live	VR	CBAA

Table 5.2. Virtual Welding Training Session Protocol

Weld Pass	Virtual Parameter Cue Employed
1. Practice Weld One	Travel Speed Cue
2. Practice Weld Two	Position/Aim Cue
3. Practice Weld Three	Travel/Work Angle Cue
4. Practice Weld Four	Contact To Workpiece Distance Cue
5. Test Weld	None

Table 5.3. Virtual Parameter Cues and their Functions

Parameter Cue	Function
Travel Speed cue	Measure the speed at which the user welds, indicates user to slow down or speed up.
Position cue	Display the aim of the weld gun, indicates user to aim at the joint of the weld.
Travel/Work Angle cue	Display the lateral and vertical angles of the weld gun, indicates the correct weld gun angles.
Contact To Workpiece Distance cue	Measure the distance between the weld gun contact tip to the workpiece, indicates the appropriate arc length.

Table 5.4. Participant Demographics (N = 108)

Item	*f*	%
Gender		
Female	53	49.1
Male	51	47.2
Other	2	1.9
Chose Not to Answer	2	1.9
Age		
18	10	9.3
19	23	21.3
20	19	17.6
21	18	16.7
22	16	14.8
23+	20	18.5
Chose Not to Answer	2	1.9
Dominant hand for most tasks		
Right hand	92	85.2
Left hand	14	13.0
Chose Not to Answer	2	1.9
Dominant hand for welding		
Right hand	96	88.9
Left hand	10	9.3
Chose Not to Answer	2	1.9
Academic grade level		
Freshman	16	14.8
Sophomore	33	30.6
Junior	37	34.3
Senior	20	18.5
Chose Not to Answer	2	1.9

Table 5.5. Participants' Prior Welding Experience (*N* = 108)

Item		*f*	%
Previous welding experience			
	No	71	65.7
	Yes	35	32.4
	Chose Not to Answer	2	1.9
If you have welded before, which of the following processes have you performed?			
	Shielded metal arc welding (SMAW; "Stick welding")	29	26.9
	Gas metal arc welding (GMAW; "MIG"; "wire welding")	19	17.6
	Oxy-fuel welding (OFW)	11	10.2
	Flux-cored arc welding (FCAW)	4	3.7
	Gas tungsten arc welding (GTAW)	4	3.7
	Submerged arc welding (SAW)	1	0.9
Previous welding simulation / simulator system use			
	Yes	3	2.8
	No	103	95.4
	Chose Not to Answer	2	1.9
Do you have a welding certification?			
	Yes	2	1.9
	No	104	96.3
	Chose Not to Answer	2	1.9

Table 5.6. Total Participant VRTEX Welding Scores With and Without Parameter Cue Assistance (*n* = 103)

Parameter	Cue Assistance	Mean Score	*SD*	*t*	*p*
Travel Speed	On	78.19	20.56	2.26	0.02
	Off	75.53	16.89		
Position	On	90.07	16.89	-3.72	<0.001
	Off	94.56	15.04		
Travel Angle	On	87.76	18.76	-3.13	0.002
	Off	91.12	15.97		
Work Angle	On	88.55	22.00	-3.51	0.001
	Off	92.97	16.48		
Contact To Workpiece Distance	On	87.42	19.01	-9.38	<0.001
	Off	97.62	7.98		

Table 5.7. Sequence Group One Participant VRTEX Welding Scores With and Without Parameter Cue Assistance (*n* =35)

Parameter	Cue Assistance	Mean Score	*SD*	*t*	*p*
Travel Speed	On	79.34	17.49	0.23	0.81
	Off	78.94	14.58		
Position	On	88.20	24.51	-2.03	0.04
	Off	93.05	15.05		
Travel Angle	On	89.39	15.70	-2.17	0.03
	Off	92.72	14.00		
Work Angle	On	88.45	22.75	-3.55	<0.05
	Off	96.32	10.46		
Contact To Workpiece Distance	On	87.15	19.47	-5.87	<0.05
	Off	98.30	5.88		

Table 5.8. Sequence Group Two Participant VRTEX Welding Scores With and Without Parameter Cue Assistance (*n* =30)

Parameter	Cue Assistance	Mean Score	*SD*	*t*	*p*
Travel Speed	On	73.30	25.94	0.26	0.79
	Off	72.58	17.64		
Position	On	91.39	15.06	6.79	<0.05
	Off	80.61	19.99		
Travel Angle	On	82.51	23.72	-2.26	<0.05
	Off	88.16	18.31		
Work Angle	On	87.04	24.14	-0.86	0.39
	Off	89.23	21.38		
Contact To Workpiece Distance	On	84.38	21.45	-5.06	<0.05
	Off	95.81	11.94		

Table 5.9. Sequence Group Three Participant VRTEX Welding Scores With and Without Parameter Cue Assistance (*n* =28)

Parameter	Cue Assistance	Mean Score	*SD*	*t*	*p*
Travel Speed	On	83.93	13.44	3.50	<0.05
	Off	78.80	15.10		
Position	On	91.86	19.91	-3.03	<0.05
	Off	98.44	5.19		
Travel Angle	On	91.61	15.10	-0.62	0.54
	Off	92.63	14.59		
Work Angle	On	90.94	16.87	-2.71	<0.05
	Off	95.92	7.72		
Contact To Workpiece Distance	On	91.93	13.97	-4.43	<0.05
	Off	98.83	3.63		

Figures

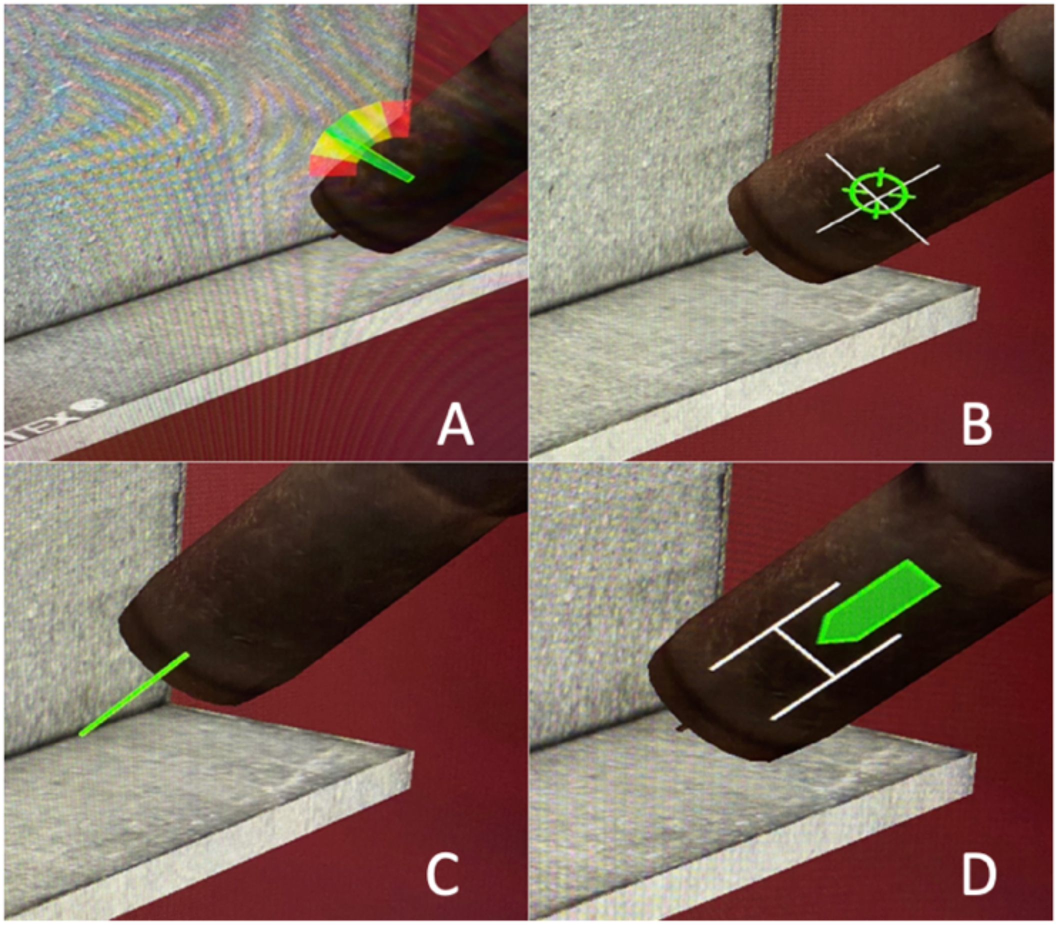

Figure 5.1 VRTEX 360 Virtual Parameter Cues. *Note.* Image A: Travel Speed cue; Image B: Work/Travel Angle cue; Image C: Position cue; Image D: Contact To Workpiece Distance cue.

Figure 5.2. VRTEX 360 Score Screen.

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VI. CONCLUSIONS

This thesis resulted in three papers that examined different aspects of virtual reality (VR) welding training methods. The first paper collected and analyzed peer-reviewed, published research regarding the implementation and use of VR technology in welding training and education. The second paper assessed the effectiveness of virtual reality integrated (VRI) gas metal arc welding (GMAW) training. The third paper compared the results of utilizing virtual parameter cues in the virtual welding environment. This chapter offers a summary of the research, general conclusions, recommendations for practice, implications for future research, and research questions.

Certain conclusions can be drawn from the results of this research. From the collection of literature published between 2012-2022 regarding VR technology in welding training and education, several trends were identified. The four major research topic themes identified across the current research were: *Comparison of Approaches, VR as a Teaching Tool, System Development,* and *System Testing.* Prevalent themes across the research recommendations were identified, including improving VR welding systems' fidelity, accuracy, and feedback, investigating the effects of virtual cues, and investigating user perceptions and learning experiences. Themes across real-world practice recommendations were identified as well, including the recommendation to utilize mobile VR systems as a cost-effective support tool for welding instructors of all kinds. Other recommendations included using the correct welding positions in a virtual welding environment, using VR to evaluate welders' performance levels, and promoting teachers and instructors to develop VR technology skills.

Results from implementing VR welding training indicate that as beginning welders receive more virtual training, their overall weld scores continue to increase. All sequence groups' welding performance progressed at a continual rate throughout the training periods. Participants consistently scored 80 and higher for their virtual welds, a score relatively high compared to weld scores resulting from traditional welding training (Stone et al., 2011). Such findings support the theory that virtual welding simulators are effective at promoting proper welding skill acquisition (Byrd et al., 2018; Stone et al., 2013; Wells and Miller, 2020). Results from our research also suggest VR welding training can provide a beneficial supplement to welding training considering every consecutive sequence group in our study achieved higher weld scores than the last.

Results from our research assessing the implementation of virtual parameter cues display a statistically significant impact on participants' weld pass rates for a single pass 2F weld. By implementing virtual parameter cues into the VRI welding training, participants performed quality welds comparable to those performed by experienced welders (Byrd et al., 2015). Our results indicate that throughout the VRI welding training, procedural knowledge of weld skill performance was developed at a faster rate than previously established rates of traditional welding training (Byrd et al., 2015; Stone et al., 2011). This exceptional training outcome is a result of the personalized feedback provided to each participant from the virtual welding simulator. The virtual parameter cues allow for a more in-depth understanding of the welding concepts and serve as a supplement to welding instruction.

Another conclusion drawn from the results of our research is that beginning welders appear to struggle the most with the travel speed welding parameter. Of the five parameter scores, all sequence groups scored the lowest on their travel speed score. This suggests travel speed could be the most difficult weld parameter for beginning welders to master, meaning they simply require more practice to perfect their speed. It could also be due to the structuring of the virtual welding training. In the virtual welding training, participants received aid from four virtual cues before they performed their test weld. The travel speed cue was the first cue they received aid from, therefore the participants could have forgotten or moved on from the visual aid provided by the travel speed cue. Lastly, this result could be due to an ineffectiveness of the virtual travel speed cue in the virtual welding environment.

Welding instructors and educators that wish to implement VR technology into their weld process training programs should provide learners with adequate practice time, employing one cue at a time. Results from analyzing the sequence group scores indicate that, when first introducing beginning welders to VR welding training, travel speed should be a key focus of training. Once they have gained some experience, the focus should shift to both position and angles of the weld gun. Finally, when the learners have more experience, they should use the VR weld training to focus on perfecting their travel speed and contact-to-workpiece-distance (CTWD). It is also recommended that once learners are capable of consistently scoring 90 or higher for each parameter and weld scores, indicating they have reached automaticity regarding that cue, they should then move on to practicing with the next cue. In line with the skills acquisition theory, training in this structured, meaningful experience will prepare beginning welders with the skill development required of potential future welders.

Additionally, instructors implementing VR into their welding training can expose apprehensive beginning students to the virtual environment before the dangerous live welding lab. Anecdotally, participants in this study, though beginning welders, were comfortable around the VR welding equipment and expressed lower levels of anxiety and apprehension compared to entering the live welding lab. Approachability of VR welding training could play a key benefit in future integration. Instructors are also recommended to use VR welding training technology in such a way that allows experienced welders to fine-tune their existing welding skills. Virtual welding training may not be necessary for all skill-levels of welders, but it can provide supplementary practice without consuming the materials typically used up in traditional welding training and practice.

Future research investigations of VRI welding training should utilize the virtual and audial parameter cues. Research should investigate effects of these cues on various weld configurations and process performances, larger sample sizes, and longer training durations. For this study, a basic 2F weld using the GMAW process was elected when considering simplicity and level of skill required in the Introduction to Agricultural Engineering course. It is recommended that further replication involving groups of beginning welders include VR training for more complex weld configurations including horizontal, vertical, and overhead positions, as well as different weld processes (e.g., shielded metal arc welding, gas tungsten arc welding, and flux cored arc welding). Due to the limited number of participants in this study, it is recommended that this study be replicated involving a larger sample size. By including more participants, a greater understanding of parameter cues' effects on beginning welders may be realized.

Research involving VR welding training should also make a point to track the amounts of metal, gas, wire, and electricity "used" within the virtual welding environment. Such information would express cost savings resulting from VR technology integration, which has yet to be fully understood. The environmental impact from VRI welding training should also be investigated.

The results and conclusions of this study raise questions that permit further research regarding the effects of VRI welding training on beginning welders, effects of virtual cue implementation in virtual welding training, and sequencing of VRI welding training. These research questions include:

1. What is the most effective way to incorporate VR technology into welding training?
2. Which sequence is the most effective for employing virtual parameter cues in a virtual welding environment?
3. How will virtual cue implementation in the virtual welding environment affect live weld performance?
4. What are the long-term effects of VR welding training?
5. Should VR welding training be provided to beginning welders before or after live welding training? And how does this impact their weld performance?
6. How does the implementation of VR technology into welding training impact training costsjfk

APPENDIX SECTION
Appendix A. IRB Approval Forms

TEXAS STATE UNIVERSITY

The rising STAR of Texas

In future correspondence please refer to 7690

February 24, 2021

Ryan Anderson, Ph.D.
Texas State University
601 University Dr.
San Marcos, TX 78666

Dear Dr. Anderson:

Your application titled, '*Assessing the Sequencing of Virtual Reality Welding Instruction in Agricultural Mechanics*' was reviewed by the Texas State University IRB and approved. It was determined there are: (1) research procedures consistent with a sound research design and they did not expose the subjects to unnecessary risk. (2) benefits to subjects are considered along with the importance of the topic and that outcomes are reasonable; (3) selection of subjects are equitable; and (4) the purposes of the research and the research setting are amenable to subjects' welfare and produced desired outcomes; indications of coercion or prejudice are absent, and participation is clearly voluntary.

In addition, the IRB found you will orient participants as follows: (1) signed informed consent will be obtained only if the participant does not want to be part of this project (opt out consent); 2) Provision is made for collecting, using and storing data in a manner that protects the safety and privacy of the subjects and the confidentiality of the data; (3) Appropriate safeguards are included to protect the rights and welfare of the subjects; (4) Participants will not receive monetary compensation.

This project was approved at the Exempt Review Level
Normal in person classroom activities are authorized . This project does not involve direct contact for research activities but will be using data obtained from the classroom activities.

Check the IRB website frequently for guidance on how to protect participants. It is the expectation that all researchers follow current federal and state guidelines. Approved research activities did not indicate face-to-face research with human subjects.

The institution is not responsible for any actions regarding this protocol before approval. If you expand the project at a later date to use other instruments, please re-apply. Copies of your request for human subject's review, your application, and this approval are maintained in the Office of Research Integrity and Compliance.

Report any changes to this approved protocol to this office. Notify the IRB of any unanticipated events, serious adverse events, and breach of confidentiality within 3 days.

Sincerely,

Monica Gonzales
IRB Compliance Specialist
Research Integrity and Compliance
Texas State University

CC: Bradley Borges, Ph.D.
Lourdez Garza
Jacob Ramos
Rhett Sykora
Brittney Heibel
Samantha Schwertlech

OFFICE OF RESEARCH AND SPONSORED PROGRAMS
601 University Drive | JCK #489 | San Marcos, Texas 78666-4616
Phone: 512.245.2314 | *fax:* 512.245.3847 | WWW.TXSTATE.EDU

This letter is an electronic communication from Texas State University-San Marcos, a member of The Texas State University System.

Dr. Seth Frei, a faculty member at Texas State University, is conducting a research study to better understand how business students learn about writing short messages. You are being asked to complete this survey because you are enrolled in an undergraduate business class and can provide your perspective on business communication knowledge.

Participation is voluntary. The survey will take no longer than 15 minutes to complete. You must be at least 18 years old to take this survey.

This study involves no foreseeable serious risks. We ask that you try to answer all questions; however, if there are any items that make you uncomfortable or that you would prefer to skip, please leave the answer blank. Your responses are confidential.

Compensation for completing the survey includes possible course extra credit that you may receive. An alternative for equal credit is available. Please contact your instructor for details.

Possible benefits from this survey include a better understanding of how to prepare students to write short messages in the workplace. This research will be beneficial to instructors preparing students for the workplace.

Reasonable efforts will be made to keep the personal information in your research record private and confidential. Any identifiable information obtained in connection with this study will remain confidential and will be disclosed only with your permission or as required by law. The members of the research team, the funding agency (remove funding agency if study is not funded), and the Texas State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.

Your name will not be used in any written reports or publications which result from this research. Data will be kept for three years (per federal regulations) after the study is completed and then destroyed.

You will receive course extra credit from your instructor for completing this study.

If you have any questions or concerns feel free to contact Seth Frei:

Dr. Seth Frei, Lecturer
Management Department
512-245-4089
sethfrei@txstate.edu

This project 7690 was approved by the Texas State IRB on February 24, 2021. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Denise Gobert 512-716-2652 – (dgobert@txstate.edu) or to Monica Gonzales, IRB Regulatory Manager 512-245-2334 - (meg201@txstate.edu).

If you would prefer not to participate, please do not fill out a survey.

If you consent to participate, please complete the survey.

Appendix B. Data Collection Instruments and Consent Documents

Questionnaire development

Trent Wells <KevinWells@saumag.edu>
Wed 10/13/2021 11:32 AM
To: Heibel, Brittney
Cc: Anderson, Ryan G

Hello Brittney,

Thank you for reaching out to me. Feel free to use my instrument in your research. Good luck. Have a great day.

Regards,

Trent Wells, Ph.D.
Assistant Professor of Agricultural Education
Department of Agriculture
Southern Arkansas University
ktwells@saumag.edu
(205) 471-1303 (cell)
(870) 235-5410 (office)

Pre- and Post-Test Survey Adaption Approval from Dr. Trent Wells

Demographic Data Survey Questions

1. What is your age? ______ years
2. What is your gender? _______________
3. What is your dominant hand for most tasks?
   ____Right
   ____Left
4. What is your dominant hand for welding?
   ____Right
   ____Left
5. What is your academic major? ________________________
6. What is your academic grade level?
   _____ Freshman
   _____Sophomore
   _____ Junior
   _____ Senior
   _____ Graduate
7. Have you ever welded before?
   ____ Yes
   ____ N
8. Have you ever used any of the following processes, if so, which?
   _____Shield Metal Arc Welding (SMAW or "Stick Welding")
   _____Gas Metal Arc Welding (GMAW or "MIG" or "Wire Welding")
   _____ Flux Cored Arc Welding (FCAW)
   _____Submerged Arc Welding (SAW)
   _____ Oxy-Fuel Welding (OAW)
   _____ Gas Tungsten Arc Welding (GTAW or "TIG")
   _____None of the above
9. If you have welded before, where were you given the opportunity to weld or practice welding?
   _____ At my family's farm or business
   _____ At a farm or business not owned by my family
   _____ In my high school's Agricultural Education program/class
   _____ In my high school's Industrial Technology program/class
   _____ Other location (please specify): __________________________________

10. Have you ever used a welding simulation / simulator system before?

____ Yes

____ No

11. Do you have any prior experience using VRTEX 360 virtual reality welding?

____ Yes

____ No

12. Do you have any prior experience using REALWELD computer-based audio assisted welding?

____ Yes

____ No

13. Have you ever completed an agricultural mechanic project for a local or county show?

_____Yes

_____ No

14. Have you ever completed an agricultural mechanic project for a major show?

_____Yes

_____No

15. Do you have a welding certification?

_____ Yes

_____ No

VRTEX 360 Virtual Reality Welding Training Session Data Collection Tables

ROUND 1

Run	Cue	Travel Speed Score	Position Score	Travel Angle Score	Work Angle Score	CTWD/ Score	Overall Score
Practice Run 1	Travel Speed						
Practice Run 2	Position Cue						
Practice Run 3	Travel/Work						
Practice Run 4	CTWD						
Test Run	(No Cues)						

ROUND 2

Run	Cue	Travel Speed Score	Position Score	Travel Angle Score	Work Angle Score	CTWD/ Score	Overall Score
Practice Run 1	Travel Speed						
Practice Run 2	Position Cue						
Practice Run 3	Travel/Work						
Practice Run 4	CTWD						
Test Run	(No Cues)						

ROUND 3

Run	Cue	Travel Speed Score	Position Score	Travel Angle Score	Work Angle Score	CTWD/ Score	Overall Score
Practice Run 1	Travel Speed						
Practice Run 2	Position Cue						
Practice Run 3	Travel/Work						
Practice Run 4	CTWD						
Test Run	(No Cues)						

REALWeld Computer-Based Audio Assisted Welding Training Session Data Collection Tables

ROUND 1

Run	**Arc ON/OFF**	**Work Angle Score**	**Travel Angle Score**	**CTWD Score**	**Travel Speed Scores**	**Position Score**	**Overall Score**
Practice Run 1	Arc OFF						
Practice Run 2	Arc OFF						
Practice Run 3	Arc OFF						
Practice Run 4	Arc OFF						
Test Run 1	ARC ON						
Test Run 2	ARC ON						

ROUND 2

Run	**Arc ON/OFF**	**Work Angle Score**	**Travel Angle Score**	**CTWD Score**	**Travel Speed Scores**	**Position Score**	**Overall Score**
Practice Run 1	Arc OFF						
Practice Run 2	Arc OFF						
Practice Run 3	Arc OFF						
Practice Run 4	Arc OFF						
Test Run 1	ARC ON						
Test Run 2	ARC ON						

ROUND 3

Run	**Arc ON/OFF**	**Work Angle Score**	**Travel Angle Score**	**CTWD Score**	**Travel Speed Scores**	**Position Score**	**Overall Score**
Practice Run 1	Arc OFF						
Practice Run 2	Arc OFF						
Practice Run 3	Arc OFF						
Practice Run 4	Arc OFF						
Test Run 1	ARC ON						
Test Run 2	ARC ON						

ROUND 4

Run	Arc ON/OFF	Work Angle Score	Travel Angle Score	CTWD Score	Travel Speed Scores	Position Score	Overall Score
Practice Run 1	Arc OFF						
Practice Run 2	Arc OFF						
Practice Run 3	Arc OFF						
Practice Run 4	Arc OFF						
Test Run 1	ARC ON						
Test Run 2	ARC ON						

ROUND 5

Run	Arc ON/OFF	Work Angle Score	Travel Angle Score	CTWD Score	Travel Speed Scores	Position Score	Overall Score
Practice Run 1	Arc OFF						
Practice Run 2	Arc OFF						
Practice Run 3	Arc OFF						
Practice Run 4	Arc OFF						
Test Run 1	ARC ON						
Test Run 2	ARC ON						