Journal of Agricultural Education, 65(1),210 - 225
https://doi.org/10.5032/jae.v65i1.2468

Integrating Virtual Reality Technology into Beginning Welder Training Sequences

Brittney Heibel[1]
Ryan Anderson[2]
Marshall Swafford[3]
Bradley Borges[4]

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 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 adequate 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 VR welding training participants' test weld scores continuously increased, as well as consistently scoring 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 (Bland-Williams, 2017). Not only does this job require great skill, but 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 (Sangwan, et al., 2016). In the past, these skills have been taught and developed through traditional welding training, comprised of repetitious and secluded training environments (Bland-Williams, 2017). Unfortunately, traditional welding training is often costly and time-intensive (Whitney & Stephens, 2014), two characteristics that threaten the welding industry as there exists a projected welder deficit of roughly 366,000 welders by 2026 (American Welding Society, 2022). 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.

[1] Brittney Heibel is a Graduate Student of Integrated Agriculture in the Department of Agricultural Sciences, at Texas State University, 601 University Dr., San Marcos, TX. 78666, bheibel55tx@txstate.edu.

[2]Ryan Anderson is an Assistant Professor of Agricultural Education & Mechanics in the Department of Agricultural Sciences, at Texas State University, 601 University Dr., San Marcos, TX. 78666, r_a461@txstate.edu. ORCID# https://orcid.org/0000-0003-3219-7680

[3]Marshall Swafford

[4] Bradley Borges is a Senior Lecturer of Agricultural Mechanics in the Department of Agricultural Sciences, at Texas State University, 601 University Dr., San Marcos, TX. 78666, b_b518@txstate.edu.

Throughout welding training, various factors affect a welders' ability to develop proper welding skills including individual backgrounds/abilities, cognitive capacity, and psychomotor dexterity (Wells & Miller, 2020). 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 (AWS, 2022). 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 (AWS, 2022). 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 (AWS, 2022). 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 (AWS, 2022).

All these components of welding, along with learning the machine settings (i.e., voltage and amperage settings) and equipment setup (i.e., welding wires, leads, guns, and gun attachments) are crucial when learning this fabrication skill (Sangwan, et al., 2016, 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 decreasing consumable costs, reducing emission pollution, increasing accessibility, and diminished training time, all while still providing effective learning opportunities for welders of all skill levels (Whitney & Stephens, 2014). 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 (Potonjak, et al., 2016, Stone, et al., 2013, Yunus, et al., 2011). Various CBAA welding training technologies involve real-life training methods supplemented with audial coaching and cues from these 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 and the results of the final live weld test session.

Virtual Reality Welding Training

Virtual reality technology, an advanced modern resource, is now commonly integrated into training throughout several skills-based professions. Virtual reality technology is used in training methods for industries such as aviation, surgery, engineering, construction, and countless more (Whitney & Stephens, 2014, Bailenson, et al., 2008). Virtual reality technology allows for computer-generated simulations to create a virtual environment in which users experience and conduct various training tasks. Over the course of several years, simulations have become more advanced than researchers had initially imagined (Helsel, 1992, Virtual Reality Society, 2020). Virtual reality 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 (Wells & Miller, 2020). More specifically, VR welding training simulations have seen great benefits to training beginning welders (Byrd, et al., 2018). 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 (White, at al., 2010). 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 (Whitney & Stephens, 2014). Learners that participate in traditional welding training are exposed to sparks, burning gas, metal fumes, and ultraviolet radiation (Stone, et al., 2013), which can be concerning for inexperienced welders (AWS, 2022). During VR training, all these events are simulated to the user virtually, rendering them safe from common dangers of traditional welding training (Whitney & Stephens, 2014). 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 (Morozova, 2018). Not only does the virtual environment protect users from welding hazards, but it aids in maintaining anxiety levels for beginning welders as well (Byrd, et al., 2018). As welding is a task demanding advanced focus and skill, increased levels of anxiety are likely to affect weld quality and job performance (Byrd, et al., 2018). Utilizing VR weld process training revealed that anxiety levels directly affected the ability of welders to perform welds that pass visual inspections. Removing stressors commonly found in traditional welding training equipment, VR training creates the advantage of a less stressful learning environment, allowing for better concentration on welding skill development (Byrd, et al., 2018).

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 (Whitney & Stephens, 2014, Dalto, et al, 2010). Virtual reality welding simulators, such as the Lincoln Electric VRTEX 360, include software systems that afford straightforward, realistic set up tasks (Lincoln Electric, 2021). 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. Virtual reality 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 (2014) 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' welding skill acquisition through more experience.

Whitney & Stephens (2014) were able to calculate 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 (Stone, et al., 2011) 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 (Stone, et al., 2011). 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 (Chan & Leijtaan, 2012, 19). Administering meaningful learning is especially important for beginning learners in that it facilitates knowledge creation and retention (Shoulders & Myers, 2013). 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. Chan & Leijtaan (2012) 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, Byrd, et al. (2018) observed an increase in welder dexterity with the use of instant and accurate feedback from VR welding simulation training. Byrd, et al. (2018) 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 cost associated with purchasing the VR training systems. 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 (Whitney & Stephens, 2014). 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 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., requiring 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 (Wells & Miller, 2020).

Theoretical Framework

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 (Ausubel, 2012). 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 (Ausubel, 2012). 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 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 (Topping, et al., 2017). 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

(Topping, et al., 2017). 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 (Topping, et al., 2017). 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 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).

Table 1

Characteristics of Three Peer Learning Methods

	Three Methods of Peer Learning		
Peer Learning Characteristic	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.

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. Furthermore, the beginning welders are able to observe their peers using the VR welding training systems while the five welding parameter scores are being displayed. 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 test 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). Virtual reality 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' test welds performed during the final live welding training session; and
3. 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 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 (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. 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 2.

Table 2

Weld Process Training Sequences for the Four-Week Welding Training involving Virtual Reality (VR), Computer-Based Audio Assisted (CBAA), and Live Weld 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	VR	CBAA	Live	Live Weld Test
Sequence Group 2	CBAA	Live	VR	Live Weld Test
Sequence Group 3	Live	VR	CBAA	Live Weld Test

Participants then underwent one VR welding training session, computer-based 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 gas metal arc welding (GMAW) process in all three training sessions. 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.

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 training process, 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 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.

Table 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

Virtual Parameter Cues

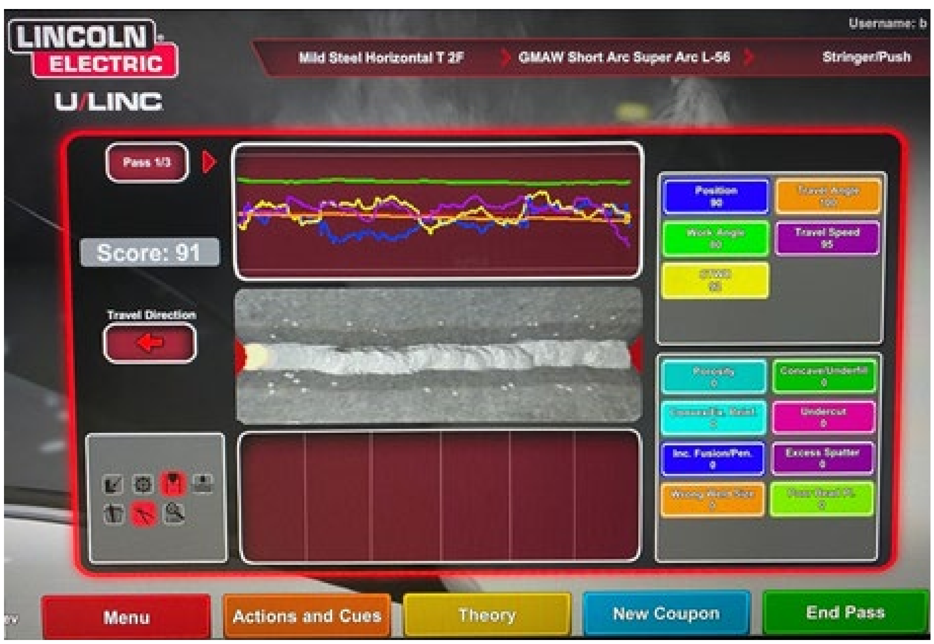
The visual parameter cues utilized in this research manifest in the virtual welding environment as gauges or icons, located at the tip of the user's weld gun. The Travel Speed cue measures the speed at which a user moves their weld gun across their workpiece, presenting as an arrow gauge. If the user's 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 as seen in Figure one. 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.

Figure 1.

Score screen of the Lincoln Electric VRTEX 360 Virtual Welding Simulator



Traditional Live Welding Training

As previously noted, 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 University 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 final 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 majority of them were sophomores and juniors (f = 33, 37). Approximately 65% of the 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.

Table 4

Participant Demographics and Welding Experience (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

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 5.

Table 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		

As illustrated previously, all participants completed the virtual welding training in different sequence groups, therefore data from individual sequence groups was analyzed. Table 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. Participants in this sequence group produced a mean score of 82.11 (*SD* = 7.79) on the live weld submitted to the CWI.

Table 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 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. Participants in this sequence group produced a mean score of 84.67 (*SD* = 3.80) on the live weld submitted to the CWI.

Table 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 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. Participants in this sequence group produced a mean score of 84.07 (*SD* = 3.71) on the live weld submitted to the CWI.

Table 8

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

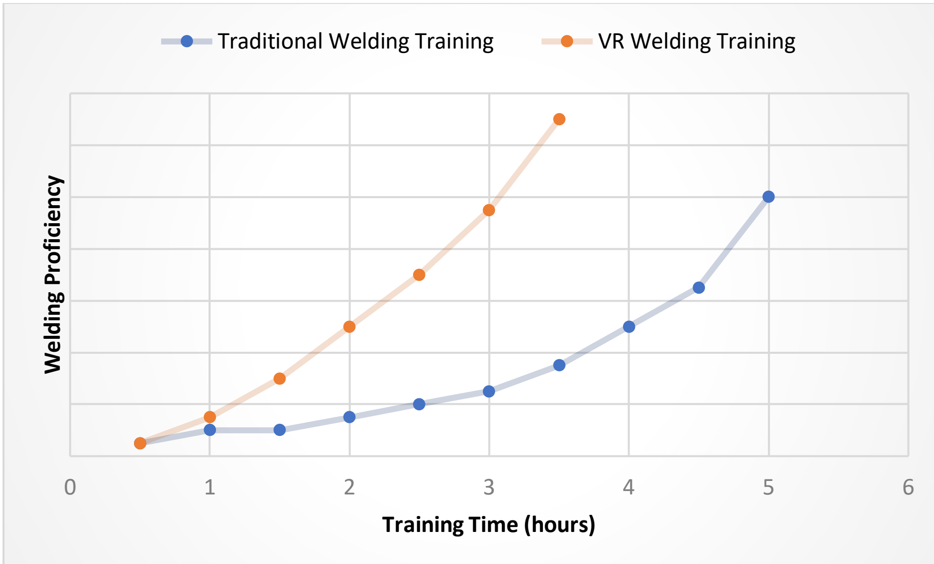
Weld Scored	Mean Score	*SD*	*t*	*p*
Round 1 Test Run	85.14	5.89	0.96	0.34
Round 2 Test Run	86.79	5.30	2.71	<0.05
Round 3 Test Run	84.86	12.48	0.33	0.74
Live Weld (CWI Grade)	84.07	3.71		

Discussion

Results from this research indicate that with each round of VR welding training, participants' test weld scores continuously improved. 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 (Stone, et al., 2011). 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 result 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 used by the AWS CWI. 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 experience 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, the participants had completed 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.

Figure 2.

Projected proficiency development of welding trainees through VR and traditional welding training



It is fully understood that developing these complex welding skills is no easy task, however, incorporating VR welding training can decrease the amount of required training time while still increasing welding skill retention. Participants in this study received only one VR welding training session, along with three separate welding training sessions. With such impressive mean pass rates resulting from a small amount of training time, it is a clear indicator that VR decreases required training time for beginning welders, and supports findings from similar studies (Stone et al., 2011; Stone et al., 2013; Wells & Miller, 2020; Whitney & Stephens, 2014; Yunus et al., 2011). Furthermore, participants' demeanor during the virtual weld training was relatively more relaxed compared to their experience of live welding training. Participants were unafraid to attempt the welds and in fact, became immersed in the welding environment as more of a video-game competition than an educational experiment. This behavior throughout our study supports the idea that exposing beginning welders to the weld process in a VR environment can be more comfortable and effective for the learner (Yunus et al., 2011). Instead of immediately placing the learner into the live welding lab, giving an introductory lesson in the VR environment may lead to the learner's increased confidence in the live welding lab later.

There exists obvious concern for the reliability of weld quality grades assigned by VR welding training simulations (White et al., 2011). VR welding simulation technology, though relatively new to educational environments, is programmed to mimic the grading parameters of industry respected CWIs. In this study, mean scores for Test Welds performed and graded using the VRTEX 360 (80.11, 82.43, and 83.11) were comparable to the Live Weld mean score (80.66) graded by a CWI. This outcome suggests that the factory quality-grading settings of the VRTEX 360 used in the study are in close alignment with the quality-grading parameters used by the AWS CWI. To adequately train beginning welders, industry and professional standards must be upheld to ensure that learners receive the entry-level skills required of the welding sector.

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

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.

Recommendations for future research and practice involving VR welding training have been developed from the results of this study. Future research investigating the individual welding parameter scores should be conducted to identify the professional development needs of beginning welders. Knowing what parameters that beginning welders struggle with the most will improve the effectiveness and efficiency of VR welding training methods. Results from this particular study indicate that the VRTEX 360's visual parameter cues assist learners in understanding the complex skills and weld quality parameters required in the welding process as their scores continued to improve as the progressed through each round of virtual training. Welding parameters comprise a majority of welding training, therefore utilizing these cues may enhance training methods immensely. We recommend future researchers replicate this study with a larger sample size to improve reliability and to determine if there were any statistical differences in the scores during the week that the students were trained using the VRTEX 360. We also recommend future replication utilizing more complex weld configurations, materials, and processes. Out of position welds and configurations such as overhead and pipe require longer durations of practice and skill development.

Additionally, further research should track the exact amount of metal, gas, wire, and electricity saved by utilizing the VRTEX 360 VR welding training simulator. By utilizing a virtual welding training environment, welders can spend more time welding and fine-tuning their skills without the burden of using materials and expenses until they are ready to move into the live welding environment. Research that involved virtual welding training should record and calculate the total savings from integrating these technologies as, although already realized by researchers, such information would further build the understanding of cost savings from integrating VR technology into welding training sequences (Morozova, 2018; Stone et al., 2011; Whitney & Stephens, 2014). The cost savings from reduced consumable usage and training time has been touted as the major benefits of VR training, the equipment cost has been cited as the major barrier. Knowing that the VRTEX 360 VR welding training simulator has a high upfront cost, we recommend educators pursue green initiative, technology-based, workforce development and/or STEM-based grants to purchase enough machines to ensure students have enough one on one time to gain meaningful learning while reducing our carbon footprint.

Future research integrating VR welding training are also recommended to provide extensive lengths of training sessions. The purpose behind this extended training time is to allow learners ample time to familiarize themselves within the virtual environment. Though the VRTEX 360 virtual welding simulator training system is simple in function and easy-to-use, the virtual environment can be disorienting at first (Byrd et al., 2018). Further, providing ample practice time is key in achieving meaningful learning as it allows learners to move from simple repetitious learning to practicing self-regulated learning (Ausubel, 2012). Existing research has investigated the use of VR welding training methods with similar timeframes as this study, therefore extended training times are recommended for future research and investigation (Stone et al., 2011; Stone et al., 2013; Wells & Miller, 2020).

Instructors that plan to incorporate VR welding training simulations are recommended to allot ample amounts of training time for their learners, as this enhances the learners' welding skill acquisition and performance. Increased welding practice time ultimately leads to increased welding skill performance

(Wells & Miller, 2020; Whitney & Stephens, 2014). The impact of including virtual welding training methods into welding training sequences is yet to be determined, however it is known that it can play a beneficial role. While participant interviews were not conducted as part of this study, anecdotally, the beginning welders reported comfort using the VR equipment and expressed lower levels of anxiety and apprehension than when using live welding equipment. It is recommended that researchers include participant interviews in future research to determine how introducing welding to beginners using VR methods impacts the time required to train them adequately. Further practice, as well as research, is required to understand the crucial role that virtual reality technology will play in the future of the welding industry.

References

American Welding Society. (2022). AWS - highlighting the welding workforce demand in the U.S. *Welding Workforce Data*. Retrieved from https://weldingworkforcedata.com/

Ausubel, D. P. (2012). *The acquisition and retention of knowledge: A cognitive view.* Springer Science & Business Media, 2012. doi: 10.1007/978-94-015-9454-7

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., and Jin, M. (2008). The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context. *Journal of the Learning Sciences,* 17(1), 102 to 141. doi: 10.1080/10508400701793141

Bland-Williams, S. (2017). *Varying Feedback Strategy and Scheduling in Simulator Training: Effects on Learner Perceptions, Initial Learning, and Transfer.* Ph.D. dissertation. Norfolk, Va., Old Dominion University.

Byrd, A. P., Stone, R. T., and Anderson, R. G. (2018). Dexterity: An indicator of future performance in beginning welders. *Career and Technical Education Research,* 43(2), 195 to 213. doi: 10.5328/cter43.2.195

Chan, S. and Leijtaan, F. (2012). Using feedback strategies to improve peer-learning in welding. *International Journal of Training Research,* 10(1), 23 to 29. doi: 10.5172/ijtr.2012.10.1.23

Dalto, L., Benus, F., and Balet, O. (2010). The use and benefits of virtual reality tools for the welding training. *63rd Annual Assembly & International Conference of the International Institute of Welding*, Istanbul, Turkey

Helsel, S. (1992). Virtual reality and education. *Educational Technology*, 32, 38-42.

Lincoln Electric. (2021). *VRTEX® 360® Single User Virtual Reality Welding Training Simulator on Pallet*. Retrieved from https://www.lincolnelectric.com/en/products/K4601-1?product=K4601 1(LincolnElectric).

Morozova, A. (2018). Using Virtual Reality to prepare people with the most dangerous jobs for high-risk situations. *Jasoren*. Retrieved from https://jasoren.com/using-virtual-reality-to-prepare-people-with-the-most-dangerous-jobs-for-high-risk-situations/

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., and Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, 95, 309 to 327. doi: 10.1016/j.compedu.2016.02.002

Sangwan, K. S., Herrmann, C., Egede, P., Bhakar, V., and Singer, J. (2016). Life cycle assessment of arc welding and gas welding processes. *Procedia CIRP*, 48, 62 to 67.

Shoulders, C. W. and Myers, B. E. (2013). Teachers' use of experiential learning stages in agricultural laboratories. *Journal of Agricultural Education*, 54(3), 100 to 155. doi: 10.5032/jae.2013.03100

Stone, R., McLaurin, E., Zhong, P. and Watts, K. (2013). Full virtual reality vs. integrated virtual reality training in welding. *Welding Journal*, 92, 167-s to 174-s.

Stone, R., Watts, K., and Zhong, P. (2011). Virtual reality integrated welder training. *Welding Journal*, 90(7), 136-s to 141-s.

Topping, K., Buchs, C., Duran, D., and Van Keer, H. (2017). *E*ffective peer learning: From principles to practical implementation. *Routledge*.

Virtual Reality Society. (2020). History of virtual reality. *Virtual Reality Society*. Retrieved from https://www.vrs.org.uk/virtualreality/history.html#:~:text=In%201968%20Ivan%20Sutherland%20and,ceiling%20(hence%20its%20name)

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

White, S., Reiners, D., Prachyabrued, M., Borst, C., and Chambers, T. (2010). Virtual reality welder training. *IS&T/SPIE Electronic Imaging* eds. San Jose, California, United States. doi:10.1117/12.840473

Whitney, S. and Stephens, A. (2014). Use of simulation to improve the effectiveness of army welding training. *Defence Science and Technology Organisation* AR-016-018.

Yunus, F. A. N., Baser, J. A., Masran, S. H., Razali, N., and Rahim, B. (2011). Virtual reality simulator developed welding technology skills. *Journal of Modern Education Review*, 1(1), 57 to 62.