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Assessing the Effects of Virtual Cue Implementation in Virtual Reality Welding Training

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Abstract

Incorporating virtual reality (VR) technology into training environments has been effective as it allows training to remain safe, efficient, and meaningful. Welding training is no exception, with research highlighting benefits such as decreased welder anxiety, increased cost- and time-efficiency, reduction in material usage, and advanced levels of skill acquisition. Our research aims to provide meaningful and experiential learning to beginner welders, equipping them with entry-level welding skills while identifying their professional development needs by employing various parameter cues using the Lincoln Electric VRTEX 360+ dual user virtual reality welding training simulator. This four-week study was completed at [University] and replicated three times. Undergraduate students (N = 108) enrolled in [Course], 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 least challenging 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 participants' welding experience increased so did their welding parameter scores.

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 (Bland-Williams, 2017). Welding training is typically comprised of safety lessons, machine and lab set-up, equipment and materials knowledge, weld process techniques, and personal welding practice using the various processes and materials. Countless factors can affect a welder's ability to develop these complex skills, such as individual backgrounds or previously acquired knowledge and habits, thus making training a lengthy process at times (Wells & Miller, 2020). These time-consuming training methods are also 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 predicted welder deficit of 366,000 facing the industry by 2026, underpin the need for a more efficient method of welding training (American Welding Society [AWS], 2022).

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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 been shown to be effective, specifically because it allows training to remain safe, efficient, and meaningful (Pantelidis, 1993; Whitney & Stephens, 2014). Effective VR systems revolve around three key components: 1) user immersion, 2) ability to navigate, and 3) ability to manipulate (Helsel, 1992). VR's exceptional interactivity has led to its heavy use across diverse educational settings (Pantelidis, 1993). This technology is used in training methods for industries such as aviation, medical surgery, engineering, construction, and others (Bailenson et al., 2008; Whitney & Stephens, 2014).

VR technology creates virtual environments in which users experience and engage in various training tasks. Over the course of many years, simulations have become more advanced than researchers had initially imagined (Helsel, 1992; Virtual Reality Society, 2020), which has led to the integration of VR technology into welding process trainings. VR training simulations are customizable so that performance settings, grading parameter settings, physical environment, and user capacity can all be modified to personal or professional preference (Wells & Miller, 2020). Within these VR welding training simulations, users are immersed into a virtual welding environment through use of Oculus headsets, real-time audio generation, and three-dimensional displays of the weld puddle, metal workpiece, and welding gun (White et al., 2010). Integration of VR welding training simulations has yielded great benefits for beginning welders (Byrd et al., 2018). 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 welding training programs 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, which have been identified as concerning to inexperienced welders (AWS, 2022). During VR training, these events and characteristics are simulated to the user virtually, rendering them safe from common dangers of traditional welding training (Whitney & Stephens, 2014). VR offers an environment that is both safe and authentic to users. Welding training can be considered a dangerous activity; therefore, the use of VR is an ideal training platform (Morozova, 2018).

Not only does the virtual environment protect users from welding hazards, but it aids in reducing anxiety levels relative to live welding for beginning welders as well. 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., 2015). A study utilizing VR weld process training revealed that anxiety levels directly affected the ability of welders to perform welds that pass visual inspections (Byrd et al., 2015). The virtual training environment reduces anxiety triggers commonly found in traditional programs thus reducing stress among the learners which promotes better concentration and skill development.

In addition to providing a safer alternative to its traditional counterpart, researchers have indicated VR welding training is a more time and cost-efficient manner for training beginning welders (Dalto et al., 2010; Whitney & Stephens, 2014). VR welding simulators, such as the Lincoln Electric VRTEX 360, include software systems that provide straightforward, realistic set-up tasks for users (Lincoln Electric, 2021). Traditional welding booths require users to initiate and prepare various gas tanks, welding tools, welding machines, gun attachments, and complete other ancillary tasks. The VRTEX 360 allows users to complete all these actions within the virtual environment at a more efficient rate (Byrd et al., 2015). By using dual VR welding stations, multiple users can train on the same machine at the same time thus decreasing training time by over two hours when compared to traditional methods. (Whitney & Stephens, 2014). With less training time required for set-up and break-down tasks, paired with multi-user welding stations, more time can be devoted to increasing the learners' welding skill acquisition (Wells & Miller, 2020).

A third benefit realized by using VR technology is reduced material, consumable, and ancillary costs. (Whitney & Stephens, 2014). These researchers indicated VR welding training decreased electrical usage costs by 33% over traditional training, while maintaining a high qualification rate for all weld types. Stone et al. (2011a) reported training programs using traditional methods consumed over $240 more in materials per student than programs that incorporated at least 50% VR. This significant reduction in training costs by means of material, energy, and equipment savings suggests that VR can be a cost-effective method for welding training.

A final, and arguably most important, benefit of integrating VR technology into welding training is in its support of meaningful experiential learning (Chan & Leijtaan, 2012). Administering meaningful learning is especially important for beginning learners to facilitate knowledge creation and retention. Additionally, experiential learning provides abstract conceptualization, reflective observation, and active experimentation, resulting in more concrete educational experiences for beginning learners (Kolb, 2015). 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 (Lincoln Electric, 2021).

Researchers have 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 (Chan & Leijtaan, 2012). More recent researchers observed an increase in welder dexterity with the use of instant and accurate feedback from VR welding simulation training (Byrd et al., 2018). The same research also documented a faster rate of weld replication by implementing VR welding training. 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.

Virtual Reality Welding Training in Agricultural Education

Agricultural mechanics has been identified as a popular course content area for agricultural education students and teachers for several years. Hubert and Leising (2000) reported over 25% of Texas agricultural education students were in enrolled in agricultural mechanics courses while nearly 60% of secondary agricultural education teachers throughout the United States taught at least one agricultural mechanics course. Falling under the agricultural mechanics umbrella of the larger agricultural education profession, welding training has been a mainstay in this sector of education for teachers and students and has been the primary focus of research efforts in agricultural mechanics education for at least the past 15 years (Hainline & Wells, 2019). Due in part to the decreased credit hours devoted to agricultural mechanics in teacher preparation programs (Granberry et al., 2023; Trickett et al., 2023), welding knowledge and skills have often been reported as deficient and thus, need areas for beginning agricultural education teachers (Swafford & Hagler, 2018). Research in VR welding training has increased dramatically over the past 10 years (Heibel et al., 2023) but limited research has been conducted linking this training to agricultural education. We seek to use the findings from this research to begin to lay a foundation for training pre-service and supporting in-service teachers as virtual reality technology becomes more common in secondary and post-secondary agriculture programs (Pulley et al., 2024).

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 (DeKeyser, 2020). During the declarative stage, learners begin understanding the skills and steps required to complete a task, also called declarative knowledge (Wells & Miller, 2020). 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 (DeKeyser, 2020). 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 entered the training as beginning welders and progressed through the levels of skill development via VR welding training.

Ausubel's (2012) assimilation theory also guided our study framework, as our main interest was to provide beginning welders with meaningful learning via weld process training. The assimilation theory explains that repetitious learning, such as traditional welding training, is less effective than meaningful learning as training in the VR welding environment provides visual clues that students can use to reflect upon prior knowledge of the concept and then adjust their welding practices to improve their skills (Ausubel, 2012). Simply, repetitious learning alone is not enough to establish cognitive learning and thus retention of skills (Ausubel, 2012). 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.

Previous researchers (Stone et al., 2011b) found beginning welders who received six hours of traditional training for 2F welds produced welds with passing inspection scores less than 40% of the time. Conversely, Byrd et al. (2015) reported that experienced welders who were trained using VR maintained average scores in the 70s for selected weld types, where a VRTEX score of 80 correlates to a passing certified welding inspector (CWI) score. This study seeks to build on Byrd et al. by exploring the role VR technology and training practices play in creating meaningful learning and skill acquisition in beginning welders. Meaningful learning was to be achieved by providing visual and audio cues within the virtual training environment, welding skill development, and sufficient skill practice time over a four-week span. We envision this method of practice will reflect a new training style where beginning welders receive personalized feedback from both the VRTEX 360 welding simulator and the welding instructor, thus enhancing their skill acquisition in an expedited time frame.

Purpose and Objectives

This study aimed 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 was to identify the welding skill development needs of beginning welders by employing various parameter cues using the Lincoln Electric VRTEX 360+ dual user virtual reality welding training simulator (VRTEX 360). 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 Work Distance (CTWD), and 5) position. These scores are averaged to calculate the overall score of the weld (Lincoln Electric, 2021). Using VR welding simulators, the main objectives of this study were 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 statistically significant difference exists.

Methods and Procedures

Study Design

Our four-week descriptive study was conducted at [University] and replicated three times. All undergraduate students (N = 108) enrolled in the [Course] during the Spring 2021, Fall 2021, and Spring 2022 semesters served as our participants. Upon approval from the [University] Institutional Review Board, participants were asked to complete a paper-based demographics survey adapted from Wells and Miller (2020), 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. 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 1) to learn how to weld a single pass 2F weld using the GMAW process. Rose et al., (2015) recommended starting with the GMAW process for beginning welders. Due to the course schedule and randomization, 36 participants were assigned to each sequence group, but 35 participants in Sequence Group One, 30 participants in Sequence Group Two, and 28 participants in Sequence Group Three completed the VR training component of the study.

Table 1

Gas Metal Arc Weld Process 2F Training Sequences for Virtual Reality (VR), Computer-Based Audio Assisted (CBAA), and Live Welding Training

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

Instrumentation

To achieve our research objectives, we created the VR welding training protocol that included the welding parameter cues offered by the VRTEX 360 without overwhelming the participants by employing one cue at a time following the recommendations of Stone et al. 2011b). The VR welding training took place in the [University] Agricultural Mechanics VR laboratory, which was 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 delivered by the researcher. The researcher-developed script was assessed for face and content validity by three VR welding training experts at Lincoln Electric. 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/audio 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. Each round included five weld passes. The first four weld passes were practice runs, each performed with different parameter cue assistance. The final pass, the test run, was performed without cue assistance. Table 2 details the training protocol developed for the virtual welding training session.

Table 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

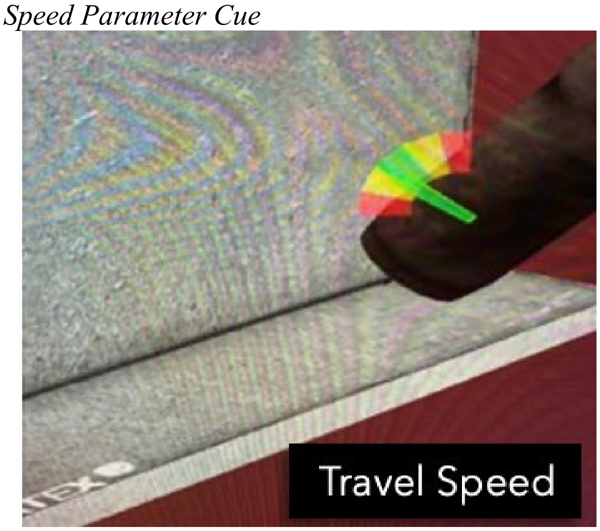
All virtual welding training sessions were scheduled for the entirety of the participants' lab period (approximately 100 minutes). However, some participant groups completed the training protocol several minutes early and were allowed to continue to use the VRTEX 360 for additional practice. This was not determined to be a limitation to the virtual training.

Virtual Parameter Cues

The visual and audio parameter cues manifest in the virtual welding environment as gauges or icons, located at the tip of the user's weld gun. The travel speed cue is presented as an arrow gauge. When the user's travel speed is too fast or slow, the cue's arrow slides into the yellow or red zones. When proper travel speed is maintained, the cue's arrow remains in the green zone (see Figure 1).

Figure 1

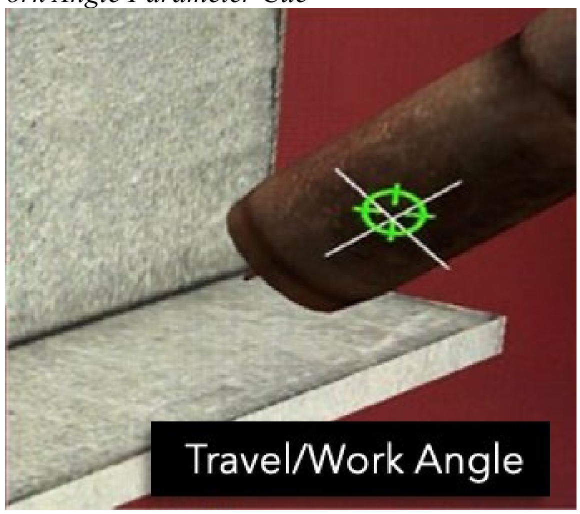
VRTEX 360 Virtual Travel Speed Parameter Cue



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 (see Figure 2).

Figure 2

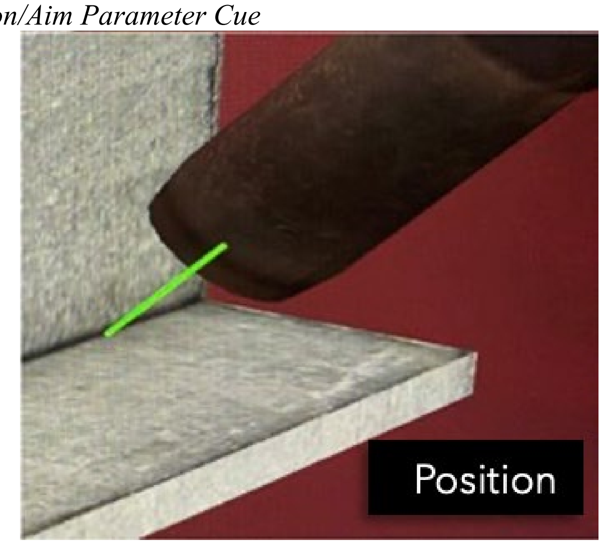
VRTEX 360 Virtual Travel/Work Angle Parameter Cue



The Position/Aim cue is a colored aim line, indicating the exact aim of the weld gun. The goal of a 2F fillet weld is to fuse two pieces of metal together; therefore, aiming directly at the joint is integral to successful fusion. A user maintaining proper aim at the joint of the weld will see a green aim line. When the user's aim drifts upward or downward, the cue line becomes yellow or red, indicating the need to reposition the weld gun (see Figure 3).

Figure 3

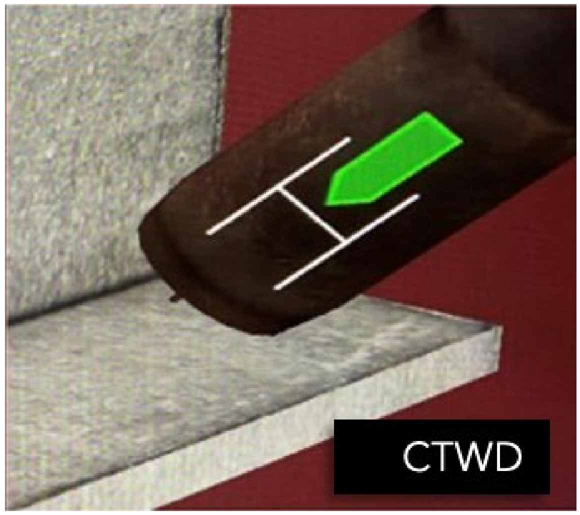
VRTEX 360 Virtual Position/Aim Parameter Cue



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. When 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 (see Figure 4).

Figure 4

VRTEX 360 Virtual CTWD Parameter Cue

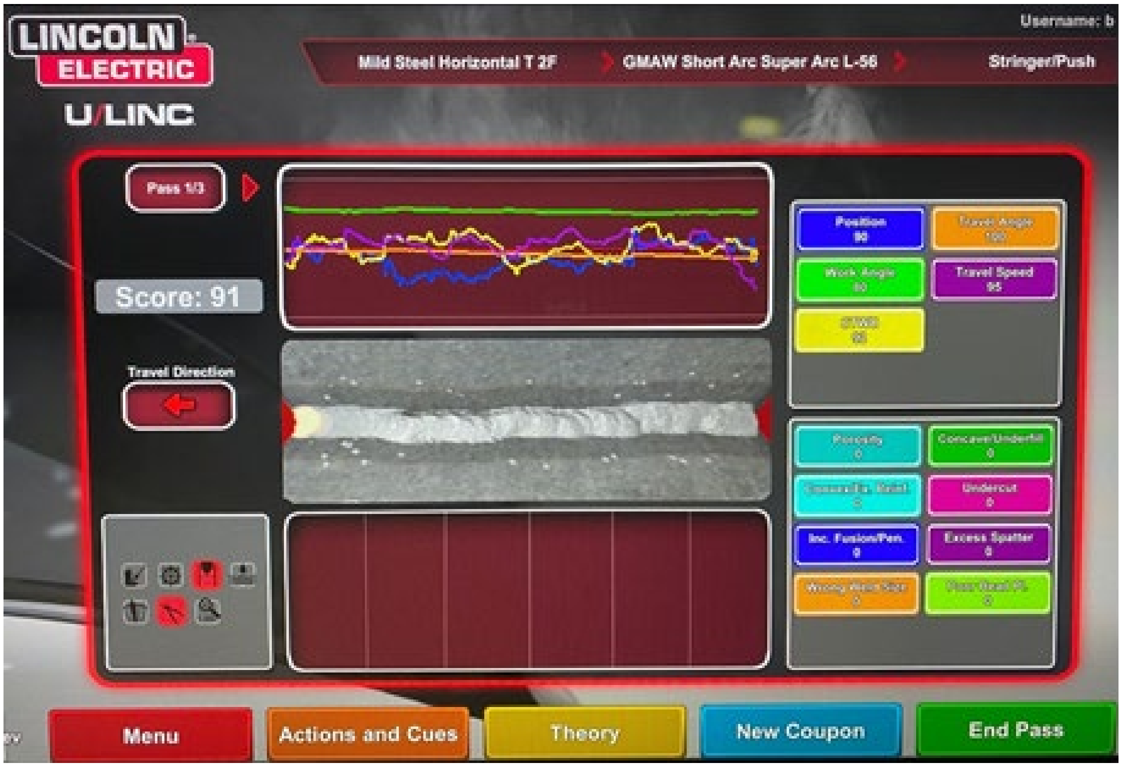


Virtual Weld Scoring

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 (see Figure 5). 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 report the score of 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. Participants then recorded their five parameter scores and overall weld score for each of the five weld passes during Round One, totaling 30 values per round. Following the completion of Round One, participants then rotated using the VRTEX 360 with their peers to complete three total rounds of the training protocol. Throughout the VR training session, participants were allowed and encouraged by the instructor to observe each other, promoting the level of meaningful and peer learning in the training environment.

Figure 5

VRTEX 360 Virtual Weld Score Screen



Results

Data were analyzed using SPSS 29.0 with selected participant demographic data presented using frequencies and percentages. Mean and overall weld scores were compared using paired-samples *t*-tests. Of the 108 participants, 53 (49.1%) identified as female, 51 (47.2%) male, and 4 (3.8%) declined to answer or selected *other*. 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%). Only three (2.8%) participants had prior welding simulator experience and only two (1.9%) participants possessed welding certifications. These and additional selected demographic characteristics are highlighted in Table 3.

Table 3

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
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

Descriptive statistics of the parameter scores for participants (n = 103) during the VR welding training are presented in Table 4. Five participants did not fully complete the training; therefore, their data was excluded from the study. The results indicated participants' parameter scores were higher when the virtual cues were off for all parameters except travel speed. All differences between parameter scores with and without cue assistance were statistically significant ($p < 0.05$).

Table 4

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

Parameter	Cue Assistance	*M*	*SD*	*t*	*p*
Travel Speed	On	78.19	20.56	2.26	0.05
	Off	75.53	16.89		
Position	On	90.07	16.89	-3.72	0.05
	Off	94.56	15.04		
Travel Angle	On	87.76	18.76	-3.13	0.05
	Off	91.12	15.97		
Work Angle	On	88.55	22.00	-3.51	0.05
	Off	92.97	16.48		
Contact To Workpiece Distance	On	87.42	19.01	-9.38	0.05
	Off	97.62	7.98		

Note. M = Mean; *SD* = Standard Deviation; $p < .05$

Data regarding Sequence Groups One, Two and Three are presented in Table Five. For clarity, when this data was collected, Group One was in their first week of training, Group Two in their second week of training, and Group Three was in their third week of welding training. The welding training that groups Two and Three had received prior to the VR training is listed above in Table One. Participants from Group One appeared to struggle the most with the travel speed parameter, with a mean score of 79.34 (*SD* = 17.49) with cue assistance and a mean score of 78.94 (*SD* = 14.58) without cue assistance. Group Two participants also struggled most with travel speed with mean scores of 73.30 (*SD* = 25.94) with and 72.58 (*SD* = 17.64) without cue assistance, respectively. Similarly, Group Three struggled the most with the travel speed parameter; however, with increased mean scores of 83.93 (*SD* = 13.44) with cue assistance and 78.80 (*SD* = 15.10) without cue assistance. Participants in Sequence Group Three continually scored an average of 90 and higher for all other weld parameters, with and without cue assistance. All three groups were able to complete the other four parameters at minimum passing rate of 80% or higher. It should be noted that the four parameter scores for each group improved after the virtual cue had been turned off with position for Group Two as the only exception. Travel speed was the only parameter to see a drop in scores from all three Groups when the virtual cue was turned off.

Table 5

Sequence Group VRTEX Welding Scores with and without Parameter Cue Assistance (N = 103)

		Sequence Group One (*n = 35)*				Sequence Group Two (*n = 30)*				Sequence Group Three (*n = 28)*			
Parameter	Cue Assistance	*M*	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
Travel Speed	On	79.34	17.49	0.23	0.81	73.30	25.94	0.26	0.79	83.93	13.44	3.50	0.05
	Off	78.94	14.58			72.58	17.64			78.80	15.10		
Position	On	88.20	24.51	-2.03	0.04	91.39	15.06	6.79	<0.05	91.86	19.91	-3.03	0.05
	Off	93.05	15.05			80.61	19.99			98.44	5.19		
Travel Angle	On	89.39	15.70	-2.17	0.03	82.51	23.72	-2.26	<0.05	91.61	15.10	-0.62	0.05
	Off	92.72	14.00			88.16	18.31			92.63	14.59		
Work Angle	On	88.45	22.75	-3.55	<0.05	87.04	24.14	-0.86	0.39	90.94	16.87	-2.71	0.05
	Off	96.32	10.46			89.23	21.38			95.92	7.72		
CTWD	On	87.15	19.47	-5.87	<0.05	84.38	21.45	-5.06	<0.05	91.93	13.97	-4.43	0.05
	Off	98.30	5.88			95.81	11.94			98.83	3.63		

Note. M = Mean; *SD* = Standard Deviation; $p < .05$

Conclusions and Discussion

The purpose of the study was to identify the welding skill development needs of beginning welders through use of VR technology. We drew several conclusions from the results of this study. First, we observed that the virtual parameter cues implemented during the VR welding training provided personalized feedback to the beginning welders that allowed them to develop fundamental welding skills that meet AWS standards within a few passes which could speed up the training timeline for beginning welders.

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 ($p < .05$) impacts on participants' pass rates for a single pass 2F weld using the GMAW process.

Byrd et al. (2015) found experienced welders, who were trained using VR techniques, could maintain average scores in the 70s for selected weld types. Our results indicated that by using parameter cues within the VRTEX 360, beginning welders performed at comparable levels to experienced welders and saw an increase in weld skill acquisition and performance. Rooted in the skills acquisition theory, the parameters scores in this study displays how participants transformed their declarative knowledge into procedural knowledge by applying their basic understanding of a concept into action thus evolving from beginning level welders with no previous experience to advanced beginner level welders that are able to meet AWS welding standards for a 2F GMAW weld. 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 welding 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 off 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 encounter nervousness or anxiety during the welding process, even in virtual environments (Byrd et al., 2015). Perhaps the nervousness or anxiety played a role in the participants ability to maintain a proper travel speed, as their anxiety increased, did their travel speed increase?

Another interesting finding within this study is that Sequence Group One, with 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 adapted to the VR environment. Group Two, with one week of prior welding training, struggled with the travel speed and position weld parameters the most. Group Three appears to have struggled only with the travel speed weld parameter. The fact that all sequence groups scored the lowest on the travel speed parameter during their test welds could indicate that the participants struggled the most with mastering travel speed or experienced 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 or had simply struggled with travel speed the most among the five welding parameters. Rose et al. (2015) indicated the GMAW process has fewer operator-controlled variables which contributed to beginning welders' success rates. The lack of focus by the participants posited in this study may be attributed to cognitive overload due to the multiple in-process variables highlighted by the VRTEX 360 during training. Inversely, because the participants were receiving practice while performing these weld passes, as well as becoming more adapted to the VR environment, this could influence 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 our study, a basic 2F weld using the GMAW process was selected when considering simplicity and level of skill required in the [COURSE]. We recommend 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 beginning welders may be realized. Additionally, as Wells and Miller (2020) 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, we recommend 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 the effectiveness of alternative cue employment sequencing within VR weld training.

Welding instructors and agricultural mechanics educators who seek to incorporate VR into their welding training programs should provide learners with adequate practice time utilizing 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 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. We also recommend 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.

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