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The Effect of Virtual Reality Technology on Welding Skill Performance

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Abstract

Simulator technologies such as virtual reality (VR) can serve as practical tools in the educational process. VR technology applications can be effectively used for weld process training. Weld process training can often be found in university-level agricultural education settings. We sought to determine if using a VR technology application within the context of a one-hour-long gas metal arc welding (GMAW) process training impacted welding skill performance as determined by certified welding inspectors (CWIs) who used a weld evaluation rubric based on American Welding Society (AWS) standards. One-hundred-and-one students from Iowa State University participated in our study. Participants were randomly placed into one of four protocol groups: (1) 100% live welding, (2) 100% VR welding, (3) 50% live welding / 50% VR welding, or (4) 50% VR welding / 50% live welding. A one-way analysis of variance (ANOVA) indicated there were no statistically significant differences (p > .05) in total weld scores between participants in the four training protocol groups. We recommend this study be replicated.

***Keywords*:** agricultural mechanics; welding; skill development; virtual reality; simulation

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Introduction

As one of many educational technologies emerging over prior decades (Saettler, 2004), simulator technologies for teaching and learning have been developed for and used in various contexts, including: (1) medicine (Cope & Fenton-Lee, 2008; Gallagher et al., 2003; Gor, McCloy, Stone, & Smith, 2003; Kilmon, Brown, Ghosh, & Mikitiuk, 2010; Kneebone, 2005; Seymour et al., 2002), (2) mine safety training (Filigenzi, Orr, & Ruff, 2000), (3) welding (Abrams, Schow, & Riedel, 1974; Byrd, 2014; Byrd, Stone, Anderson, & Woltjer, 2015; Oz, Ayar, Serttas, Iyibilgin, Soy, & Cit, 2012; Stone, McLaurin, Zhong, & Watts, 2013; Stone, Watts, Zhong, & Wei, 2011; White, Prachyabrued, Chambers, Borst, & Reinders, 2011), (4) education (Agnew & Shinn, 1990; Nadolny, Woolfrey, Pierlott, & Kahn, 2013; Perritt, 1984), and (5) first responder training (Bliss, Tidwell, & Guest, 1997). Thiagarajan (1998) described a simulation as "a representation of the features and behaviors of one system through the use of another" (p. 35). As simulator technologies have become more widespread and will continue to evolve over time to fulfill different roles (Thiagarajan, 1998), their beneficence and effectiveness are expected to be quite high (Kneebone, 2005).

Using simulator technologies for teaching and learning purposes, such as training a welder how to perform a specific weld joint configuration, can potentially positively impact skill development (Nikolic, Radivojevic, Djordjevic, & Milutinovic, 2009; Scalese, Obeso, & Issenberg, 2008). Further, using simulator technologies as part of the teaching and learning processes can help reduce anxiety

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when learning within a new skill domain (Byrd, 2014). Various technologies such as augmented reality (AR) (Lee, 2012; Yuen, Yaoyuneyong, & Johnson, 2011) and virtual reality (VR) (Youngblut, 1998) can be used to provide for a diversity of simulator technologies (Scalese et al., 2008). However, as Wenglinsky (1998) advised, the use of an educational technology alone does not necessarily result in increased achievement. Rather, using educational technology to facilitate teaching and learning, such as using a VR-based simulator technology to develop a skill set, should be done pragmatically and deliberately (Wenglinksy, 1998). As such, the selection and appropriate use of educational technology for a teaching and learning purpose should be conscientious.

The Virtual Reality Society (2017) described VR as "a three-dimensional, computer-generated environment which can be explored and interacted with by a person" (¶ 5). Scholars (Bailenson, 2018; Pantelidis, 1993) speculated VR technology could have much potential to assist with teaching and learning procedures in the coming years. Helsel (1992) echoed this sentiment by stating "[v]irtual reality holds much promise for education…[and] education has a tremendous wealth of information and experience to bring to the VR curriculum" (p. 42). Since Pantelidis's (1993) and Helsel's (1992) work, VR has continued to become further entrenched in educational settings. Bailenson (2018) postulated that as a result of rapid technological changes, VR technology holds much potential to continue impacting teaching and learning processes in the coming years.

Potkonjak et al. (2016) proposed integrating VR technology into science-, technology-, and math-based content could serve as a practical educational intervention to help students acquire content-specific knowledge and skills more efficiently and effectively. Moreover, Byrd (2014) and Stone et al. (2011) indicated using VR technology applications could be pragmatic and effective for developing welding-related psychomotor skills. As weld process training is often a component of agricultural education programs at the university level (Burris, Robinson, & Terry, 2005), perhaps this approach could be beneficial for developing psychomotor skills in the context of weld process training in university-level agricultural education.

Psychomotor skills can be described as a linkage between various cognitive and physical processes requiring physical motions and mental stimulation to successfully accomplish their objectives (Lancelot, 1944; Venes, 2017). Psychomotor skills could include such tasks as operating power machinery, performing open-heart surgery, or completing a hand-drawn sketch. Different career fields require individuals to make certain hand and body motions to perform daily tasks. For example, in the context of medical science, psychomotor skills are particularly important for surgical practitioners, as fine movements must be made to ensure safe and effective surgical practice and the health of the patient (Gallagher et al., 2003; Kaufman, Wiegand, & Tunick, 1987). In welding, a career area traditionally within the scope of agricultural education (Burris et al., 2005; Pate, Warnick, & Meyers, 2012), individuals use psychomotor skills to manipulate and maintain control over a molten weld puddle to complete various tasks (Bowditch, Bowditch, & Bowditch, 2017; Byrd, 2014).

In the application of psychomotor skills to a given setting, human-related factors such as prior experience and comfort, dexterity, and anxiety can influence performance (Byrd, 2014). Referencing the development of psychomotor skills within university-level agricultural education settings, Osborne (1986) noted the psychomotor skill development process itself could be complex and challenging yet educationally rewarding. Wulf (2007) noted developing motor skills for use in a certain context, such as the psychomotor skills used during welding activities, can take a considerable amount of time, effort, feedback, and continued practice to refine the appropriate skills. As noted by Bowditch et al. (2017), psychomotor skills used by welders can be quite varied but typically are related to hand-eye coordination, hand and arm movements, and body positioning.

Using effective strategies to enhance the acquisition of abilities in a subject area is of critical importance for continued success in the teaching and learning of skills and knowledge (Goldsmith, Stewart, & Ferguson, 2006). Phipps, Osborne, Dyer, and Ball (2008) noted technology usage is often an important part of the teaching and learning processes in agricultural education settings. Moreover, psychomotor skill development is often an objective of many aspects of agricultural education (Lancelot, 1944; Osborne, 1986; Phipps et al., 2008). Considering these concepts, perhaps using a VR technology application to develop psychomotor skills in the context of a university-level agricultural education setting could yield practical results. Stone et al. (2011) indicated individuals who used VR technology for welding skill development purposes performed comparably to, and in some cases superior to, individuals who underwent traditional weld training procedures. Thus, the potential advantages of using VR technology for weld training purposes become clearer.

Byrd (2014) suggested "VR gives participants the capability to hone task-related abilities" (p. 63). Like Stone et al. (2011), Byrd (2014) used weld process training protocols spanning several days, thus immersing his study's participants in a somewhat lengthy duration of training exposure. To date, while several studies engaging participants over longer time frames have been conducted, limited data exist describing the effects of short-duration training procedures on individuals' welding skill performance. What effects would a VR technology training approach conducted over a short time span have on weld process skill performance?

Theoretical Framework

Skill acquisition theory (DeKeyser, 2015) underpinned our study. Skill acquisition theory describes the development of skills through three stages: "declarative, procedural, and automatic" (DeKeyser, 2015, p. 95). The first step in the skill acquisition process is the understanding of the skill itself and the procedures to be performed, otherwise referred to as declarative knowledge. Declarative knowledge can be obtained in several ways, including reading about a skill performance process, observing someone else perform the skill, or watching a demonstration video. Transforming declarative knowledge into procedural knowledge is the focus of the second step. During this step, which is often rapid in nature, the application of the basic knowledge and understanding about a concept begins via practice. Practice usually lasts for an extended time and is focused on improving time to completion, accuracy, and gradually reducing the cognitive activity required to successfully complete the task.

Adequate practice is designed to help guide an individual to the third stage, automaticity (DeKeyser, 2015). As an individual continues to move toward automaticity, he or she is expected to continue improving until accuracy is high, task completion time is minimal in comparison to when the task was first being practiced, and the cognition needed for successfully addressing the skilled task has been minimized and is often inherent.

As focus is an important part of the skill acquisition process (Wulf, 2007), someone who is practicing a skill can alter his or her focus as automaticity is reached. For example, a person learning how to perform a 1G butt weld with the gas metal arc welding (GMAW) process while using a VR technology application may use visual cues provided on a heads-up display screen to help him or her understand how to properly apply travel angle theory to a virtual weld. While the skill is being understood and applied early in the practice process (i.e., entering from the declarative stage to the procedural stage), he or she may focus a great deal of time looking at the visual cue instead of the virtual weld. Over time, his or her focus point may change over to the virtual weld bead being produced instead of the visual cue, perhaps even removing the visual cue entirely once adequate practice with the skill has been completed and he or she moves into the automaticity stage. As noted by several scholars (DeKeyser, 2015; Lancelot, 1944; Osborne, 1986; Wulf, 2007), learning how to successfully acquire and apply skills is a process requiring physical and mental exertion to achieve success.

When examining the application of skill acquisition theory into our study, our primary focus was on welding skill application and performance in the context of a structured one-hour GMAW process training session conducted by the lead researcher. We sought to apply the theoretical process of skill acquisition (DeKeyser, 2015) into each of the structured training protocols we used. Four different training protocols incorporating varying levels of VR technology application usage were applied in our study. We conducted the training protocols with participants from different backgrounds and varying levels of prior experiences with the GMAW process. Through this approach, we were able to apply the different stages of skill acquisition (i.e., declarative, procedural, and automatic) into all four training protocols and work directly with participants during each stage.

The declarative stage occurred through the lead researcher's verbal instruction and visual demonstration of the skill of focus, which was producing 2F tee joint welds using the GMAW process. Each participant then entered the procedural stage and was allowed solo, semi-supervised practice for a designated amount of time. The amount of time for practice varied based upon the training protocol each participant was randomly assigned to. The objective of the practice session was to provide adequate time for basic skill conceptualization and application to occur and allow for procession into the automaticity stage. Afterward, a brief testing session occurred for us to collect physical weld data for our study. As such, we used VR technology as an intervention technique within the skill acquisition process. Our chief interest was determining if using differing applications of a VR technology application for weld process training purposes had any impact on welding skill performance.

Purpose

The purpose of our study was to determine the effects of differing applications of VR technology usage on welding skill performance during a one-hour-long GMAW process training session. Our study aligned with the American Association for Agricultural Education National Research Agenda Research Priority Area 3: Sufficient Scientific and Professional Workforce That Addresses the Challenges of the 21st Century (Stripling & Ricketts, 2016). As the agricultural industry continues to change (Doerfert, 2011), a workforce capable of addressing the challenges and needs of the future will be vital (Stripling & Ricketts, 2016).

To help prepare future members of the agricultural industry workforce, such as school-based agricultural education (SBAE) teachers, effective and appropriate instructional practices should be used to ensure adequate and useful skills, such as GMAW process theory and welding equipment use, are being developed and transferred. We postulated technology-based applications may be capable of playing a pragmatic role in this process. Lindner, Rodriguez, Strong, Jones, and Layfield (2016) noted technology is evolving and should be used to help solve problems facing agriculture currently and in the future. As Stone et al. (2011) indicated, using a VR technology application could be a practical method to help address workforce development needs.

Research Hypothesis

H_1: Using VR technology to facilitate the development of welding skills to complete 2F tee joints will result in a significant impact on total weld scores.

Methods and Procedures

Recruitment Procedures and Participant Information

Our study was conducted during the Fall 2018 semester and consisted of undergraduate and graduate students enrolled at Iowa State University (ISU). After the ISU Institutional Review Board (IRB) approved our study, we invited all students majoring in Agricultural and Life Sciences Education (n = 186), Agricultural Studies (n = 338), Agricultural Education and Studies (n = 70), Agricultural Engineering (n = 229), Agricultural and Biosystems Engineering (n = 84), Agricultural Systems Technology (n = 170), Industrial Technology (n = 290), and Mechanical Engineering (n = 2,424) to participate via e-mail. We invited the students in these academic majors based on the lead researcher's experiences with students' interests in a welding-focused agricultural mechanics course taught by him. In addition to the e-mail sent to 3,791 students, the lead researcher used in-class announcements to recruit the 38 students enrolled in the two agricultural mechanics courses he taught. The students in these two courses were part of the group of 3,791 ISU students who had been sent the invitational e-mail.

Within the invitational e-mail and the in-class announcements, students were asked to use a Doodle poll to select one participation time slot best suited their personal schedules. To help incentivize students to participate, we offered a chance to win one of four $40.00 gift cards. Reminder e-mails and text messages were sent to students one day in advance of their scheduled participation time slot. Students were also invited to share information about the study with anyone they believed may be interested in participating regardless of their academic major. Students were notified via the invitational e-mail and in-class announcements they needed to wear clothing appropriate for welding activities.

We developed a paper-based questionnaire to collect participants' demographics data. The questionnaire included eight questions related to participants' gender, age, academic standing, academic major, prior welding experiences and welding simulator use, and daily video game playing time. To ensure wording clarity from the perspectives of individuals within our population of interest, we had three students in an undergraduate-level agricultural mechanics course evaluate the questionnaire. They suggested a couple minor question wording changes to improve clarity.

We added one question related to individuals' dominant hand usage and three questions related to participants' prior welding experiences to better understand how participants' welding experience may impact their welding skill performance. We had three other students in an undergraduate-level agricultural mechanics course evaluate the questionnaire to ensure each item was worded clearly. They each reported all the items on the questionnaire were worded clearly.

Research Design

Our study used a randomized posttest-only experimental research design (Campbell & Stanley, 1963; Figure 1). The posttest in our design was participants' test welds.

Producing Horizontal 2F Tee Welds Using the GMAW Process		
R	X_1	O
R	X_2	O
R	X_3	O
R	X_4	O

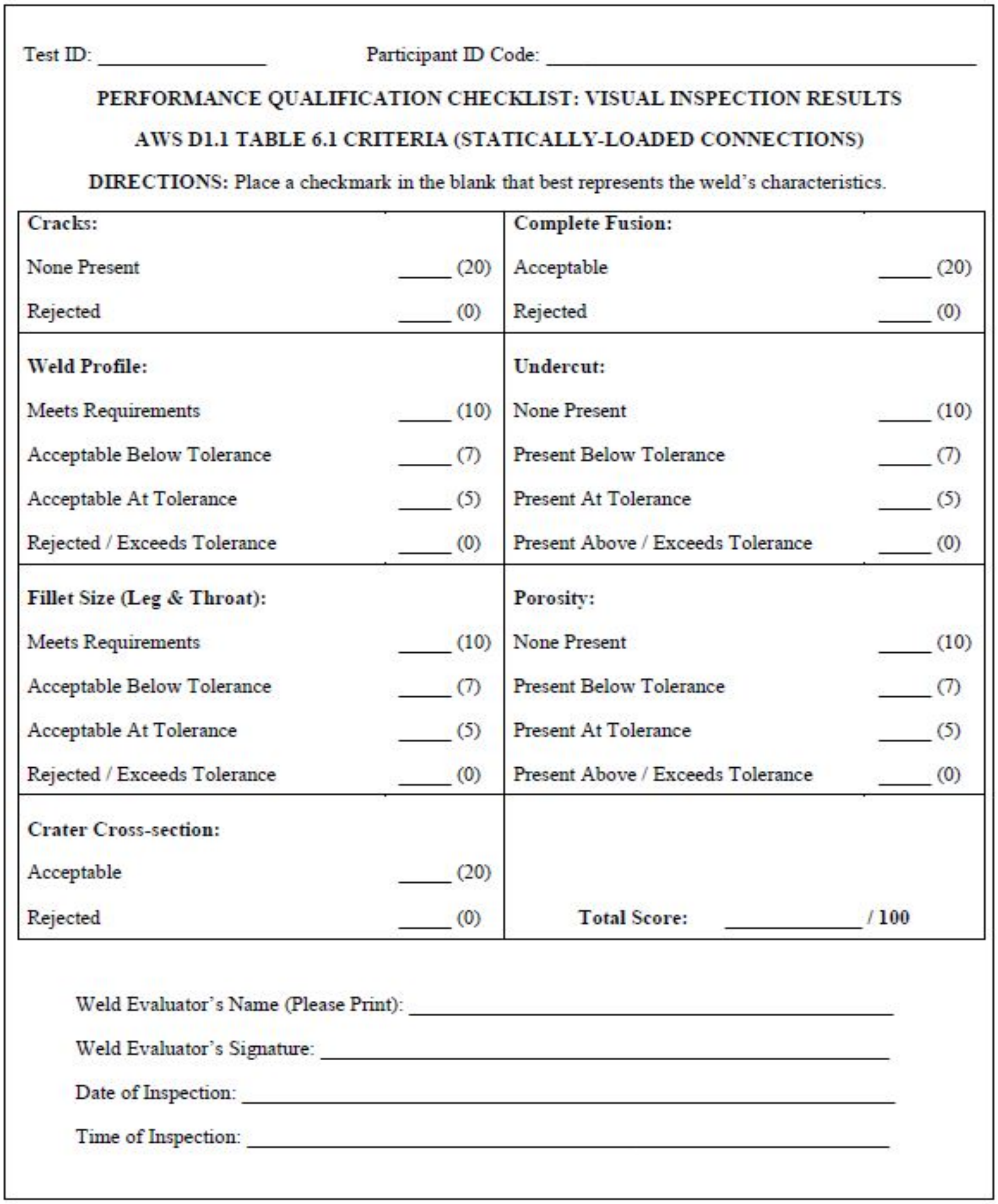
Figure 1. Illustration of randomized posttest-only experimental design. R = random assignment; O = observation of test weld produced; X_1 = 100% live welding; X_2 = 100% VR welding; X_3 = 50% live welding / 50% VR welding; X_4 = 50% VR welding / 50% live welding

Posttest-only designs are suitable for rigorous educational research and help control for a wide range of threats to internal and external validity (Campbell & Stanley, 1963). Our use of random assignment, short duration training protocols, conducting one-on-one training with each participant, detailed scripts for each training protocol group, a valid and reliable weld evaluation rubric, and recruitment of all individuals from different majors controlled for this range of internal and external threats to validity.

As noted by Campbell and Stanley (1963), using a pretest can confound research results. Had we used a research design that incorporated a pretest of welding skill performance, pretest sensitization as a threat to internal validity and testing as a threat to external validity could have resulted. Our selection of a posttest-only design helped us to avoid these issues.

Instrumentation

Participants' test welds were visually inspected and evaluated by American Welding Society (AWS)-credentialed CWIs. The CWIs used a weld evaluation rubric co-developed by the lead researcher and a CWI who did not evaluate welds for this study. The rubric was based on the AWS D1.1 Table 6.1 visual inspection criteria for statically-loaded connections and consisted of visual inspection criteria for weld cracks, the occurrence of porosity, completeness of fusion, both leg and throat fillet sizes, the presence of undercut, crater cross-section, and the weld profile. A maximum possible score of 100 points could be achieved using this rubric. The rubric is illustrated in Figure 2.



Test ID: _______________ Participant ID Code: ____________________________________

PERFORMANCE QUALIFICATION CHECKLIST: VISUAL INSPECTION RESULTS

AWS D1.1 TABLE 6.1 CRITERIA (STATICALLY-LOADED CONNECTIONS)

DIRECTIONS: Place a checkmark in the blank that best represents the weld's characteristics.

Cracks:		**Complete Fusion:**	
None Present	_____ (20)	Acceptable	_____ (20)
Rejected	_____ (0)	Rejected	_____ (0)
Weld Profile:		**Undercut:**	
Meets Requirements	_____ (10)	None Present	_____ (10)
Acceptable Below Tolerance	_____ (7)	Present Below Tolerance	_____ (7)
Acceptable At Tolerance	_____ (5)	Present At Tolerance	_____ (5)
Rejected / Exceeds Tolerance	_____ (0)	Present Above / Exceeds Tolerance	_____ (0)
Fillet Size (Leg & Throat):		**Porosity:**	
Meets Requirements	_____ (10)	None Present	_____ (10)
Acceptable Below Tolerance	_____ (7)	Present Below Tolerance	_____ (7)
Acceptable At Tolerance	_____ (5)	Present At Tolerance	_____ (5)
Rejected / Exceeds Tolerance	_____ (0)	Present Above / Exceeds Tolerance	_____ (0)
Crater Cross-section:			
Acceptable	_____ (20)		
Rejected	_____ (0)	**Total Score:**	____________ **/ 100**

Weld Evaluator's Name (Please Print): ____

Weld Evaluator's Signature: ____

Date of Inspection: ____

Time of Inspection: ____

Figure 2. Weld evaluation rubric.

After the rubric was developed, a panel of five experts was used to assess face validity and content validity. The five experts consisted of two agricultural teacher education faculty members who had taught school-based and university-level agricultural mechanics coursework including welding for at least 10 years and three AWS-credentialed CWIs who had each been actively engaged in the welding industry in various capacities over the last decade. The rubric and a panel of experts guidelines form was submitted to each panel member for an initial review.

During the review process, each panel member provided corrective feedback on both the rubric and the guidelines form. After all the panel members responded, the lead researcher made the recommended changes and re-submitted the rubric and the panel of experts guidelines form back to each panel member for a second review. During the second review, all five panel members agreed the rubric was face valid and content valid and suitable for use in the study.

After the rubric was determined to be valid and suitable for use, we conducted a pilot study during the Summer 2018 semester. The pilot study consisted of 20 undergraduate and graduate students from ISU and was intended to help us identify and correct any issues associated with the study's design and provide test weld data useful for determining the reliability of the rubric. We used Statistical Package for the Social Sciences (SPSS$^{©}$) Version 24 software to help us randomly assign 40 different participation slots. While we originally planned to have 40 participants in the pilot study, only 20 students participated. The random assignment generated by using SPSS resulted in unequally-sized training protocol groups. Consequently, we opted to use another method during the formal study's implementation in the Fall 2018 semester. The four protocol groups described in Figure 1 were used during the pilot study; participants in each group completed three test welds and chose one test weld to be evaluated by five CWIs in Iowa who volunteered to evaluate all 20 test welds from the pilot study.

Two of the five CWIs were community college-level welding program instructors while the other three CWIs were employed at a large commercial equipment manufacturing company. To determine the internal consistency of the rubric during the pilot study, we used only first-round data, which yielded a Cronbach's alpha coefficient of .714 based on standardized items. Basing the Cronbach's alpha coefficient on the standardization of items was used due to the application of differing rating levels to evaluate welds. Cohen et al. (2011) noted standardization allows for comparison between items comprised of different scales. Using the Cronbach's alpha interpretations offered by George and Mallery (2003), we determined this rubric had an acceptable level of internal consistency.

We repeated these procedures with the data collected during the formal study conducted during the Fall 2018 semester. Due to scheduling conflicts, only three CWIs who evaluated test welds during the pilot study were able to evaluate test welds during the formal study. During this second determination of internal consistency, the three CWIs evaluated all 101 test welds completed by the formal study participants. Data collected from the first-round evaluation yielded a Cronbach's alpha coefficient of .860 based on standardized items and was also determined to be adequate using the standards set forth by George and Mallery (2003).

Following the test-re-test reliability method noted by Cohen, Manion, and Morrison (2011), the 20 test welds from the pilot study were twice evaluated independently by each of the five CWIs. The first and second evaluations were conducted at least one week apart. We used intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) to determine both intra- and interrater reliability of each CWI who evaluated the test welds from the pilot and formal studies. ICCs can be used to determine the reliability of scales used in quantitative research designs (Fleiss & Cohen, 1973; Koo & Li, 2016). As noted by LeBreton and Senter (2008), "[e]stimates of IRR [interrater reliability] are used to address whether judges rank order targets in a manner that is relatively consistent with other judges" (p. 816). In contrast, intrarater reliability "is estimated by having one rater score the same instrument on two different occasions" (Scholtes, Terwee, & Poolman, 2011, p. 237).

Five CWIs independently evaluated the 20 test welds produced during the pilot study on two separate occasions at least one week apart. Intrarater reliabilities were calculated using both the first and second rounds of data while the interrater reliability was determined by using only the first-round data. Intrarater reliabilities were as follows for CWIs one through five, respectively: .710, .951, .785, .827, and .814. Interrater reliability between all five CWIs was determined to be .926. Regarding interpretation, Koo and Li (2016) noted, "ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability" (p. 158). These procedures were repeated with the test welds produced during the formal study. Intrarater reliabilities were as follows for CWIs one through three, respectively: .810, .670, and .819. Interrater reliability between all three CWIs was determined to be .863.

Procedures

All research activities took place at the ISU Agricultural Mechanics Teaching Laboratory. Prior to the implementation of the formal study, the lead researcher and another doctoral student not affiliated with our study created a chart to determine random assignment sequencing. Due to the lead researcher's time constraints, we determined the creation of 140 different hour-long participation time slots would be suitable for our research design. Four colored paper clips were drawn at random from a plastic cup 35 times to fill 140 participation time slots, thus ensuring each color was drawn 35 times to help create four equally-sized protocol groups. The color of each paper clip corresponded to a designated group. Random assignment was based on order of appearance, thus eliminating random assignment sequencing errors if a student did not attend his or her designated participation time slot. For example, if seven students were scheduled to participate over the course of a given day and only three students participated, the random assignment designations were not impacted by the four students who did not participate as the group number corresponded to the order of appearance.

The formal study was conducted on Tuesdays, Thursdays, and Fridays over several weeks during the Fall 2018 semester. Each day, seven one-hour participation time slots were available with a 15-minute interval between each one. The 15-minute interval served as a time to reset welding equipment, clean the workstations, and prepare for the next participant. Upon arrival, participants were asked to complete a 12-item demographics questionnaire and were provided with welding personal protective equipment (PPE), which included welding gloves, a welding helmet, a welding jacket, ear plugs, and safety glasses. Individuals who did not wear clothing appropriate for welding activities were not allowed to participate in the study activities and were asked to re-schedule their participation on the Doodle poll.

Four different GMAW weld process training protocols were used. Each protocol lasted for approximately one hour. Protocol one was a 100% live welding approach and included 25 participants. Protocol two was a 100% VR welding approach and included 26 participants. Protocol three was a blended 50% live welding and 50% VR welding approach and included 25 participants. Protocol four was a blended 50% VR welding and 50% live welding approach and included 25 participants. Specific information about each training protocol is depicted in Table 1.

Table 1

Weld Process Training Protocols

Protocol Number	Protocol Descriptor	Protocol Steps (Time Allowance)
1	100% live welding	Informed consent letter reading and signing, demographics questionnaire completion (10 minutes) Researcher live weld demonstration (Five minutes) Participant live weld practice (30 minutes

		Live test weld production and selection (Five minutes)
2	100% VR welding	Informed consent letter reading and signing, demographics questionnaire completion (10 minutes) Researcher virtual weld demonstration (Five minutes) Participant virtual weld practice (30 minutes) Researcher live weld demonstration (Five minutes) Live test weld production and selection (Five minutes)
3	50% live welding / 50% VR welding	Informed consent letter reading and signing, demographics questionnaire completion (10 minutes) Researcher live weld demonstration (Five minutes) Participant live weld practice (15 minutes) Researcher virtual weld demonstration (Five minutes) Participant virtual weld practice (15 minutes) Live test weld production and selection (Five minutes)
4	50% VR welding / 50% live welding	Informed consent letter reading and signing, demographics questionnaire completion (10 minutes) Researcher virtual weld demonstration (Five minutes) Participant virtual weld practice (15 minutes)

	Researcher live weld demonstration (Five minutes) Participant live weld practice (15 minutes) Live test weld production and selection (Five minutes)

The lead researcher used a detailed written script to guide each training protocol. When going through each protocol's script with a participant, the lead researcher provided technical details about the procedures he / she was expected to undergo and performed demonstrations of how to use the welding equipment to perform the 2F tee joint welds. Participants were provided with an unlimited supply of quarter-inch-thick mild steel plates to practice their welds and were allowed to ask the lead researcher questions when needed.

Participants who underwent protocol groups one, three, and four used the same Miller$^{®}$ XMT$^{®}$ 350 CC / CV Multiprocess Welder to practice their welds. Participants in protocol groups two, three, and four used the same Lincoln Electric$^{®}$ VRTEX$^{®}$ 360 to practice their virtual welds. Participants in these training protocol groups were not allowed to use the VR welding system's visual cues function but were instead provided with system-scored visual post-weld feedback for different weld technique parameters (e.g., contact-to-work distance [CTWD], travel speed, work angle, etc.). These feedback data were displayed on a computer monitor attached to the system. Due to a technical issue with the Lincoln Electric$^{®}$ VRTEX$^{®}$ 360 used in our study, participants in protocol groups two, three, and four were not able to hear any sounds associated with the VR welding process. We used a secure digital storage system to collect and save the virtual weld data produced by participants who underwent these three training protocols. The virtual weld data were not reported in this manuscript.

At the end of each training protocol, each participant was provided with six, quarter-inch-thick mild steel plates to produce three test welds using a Miller$^{®}$ XMT$^{®}$ 350 CC / CV Multiprocess Welder and subsequently selected the single best weld for evaluation by the CWIs. Participants did not use the same Miller$^{®}$ XMT$^{®}$ 350 CC / CV Multiprocess Welder to perform both their practice welds and their three test welds. All participants did use the same Miller$^{®}$ XMT$^{®}$ 350 CC / CV Multiprocess Welder to produce their three test welds. Each participant's self-selected best weld was cooled, marked with an identification code, and stored in a locked location accessible only by the lead researcher. The other two welds were placed into a designated location in the ISU Agricultural Mechanics Teaching Laboratory and were saved for metal recycling purposes.

Upon the formal study's conclusion, a debriefing e-mail disclosing the study's experimental design was sent to all pilot and formal study participants. After the formal study concluded, all 101 formal study participants' test welds were independently evaluated by three CWIs using the weld evaluation rubric previously described. When one week had passed, all 101 test welds were re-evaluated by the three CWIs. All evaluation data were compiled into an IBM SPSS Version 24.0 software data set and analyzed.

Data Analysis

To test our research hypothesis, we used a one-way analysis of variance (ANOVA) to compare the weld process training protocol groups' mean total weld scores. Our dependent variable was total weld score and our independent variable was the type of weld training protocol used. Prior to analyzing our data, we averaged the total weld scores from all three CWIs. We used Omega squared (ω^2) to calculate effect size. ANOVA and Omega squared (ω^2) are often used in tandem within quantitative agricultural education research (Kotrlik, Williams, & Jabor, 2011).

Results

One-hundred-and-one participants provided the data reported in this manuscript. Most participants were male (*f* = 87; 86.1%). The average age of the participants was 22.05 years (*SD* = 4.89). Most participants were right-hand dominant (*f* = 88; 87.1%). Nearly one-third of participants were seniors (*f* = 32; 31.7%). Over half of the participants were majoring in Mechanical Engineering (*f* = 54; 53.5%). On average, the participants spent 0.96 hours daily (*Mdn* = 0.5, *Md* = 0.0, *SD* = 1.39) playing video games. Specific details about the participants' demographics are provided in Table 2.

Table 2

Participant Demographics (n = 101)

Item	*f*	%
What is your gender?		
Male	87	86.1
Female	14	13.9
What is your age?		
18-21	64	63.4
22-25	25	24.8
26-29	5	5.0
30-33	2	2.0
34-37	2	2.0
38+	3	3.0
Which hand is your dominant hand?		
Left hand	13	12.9
Right hand	88	87.1
Please indicate your current academic standing.		
Freshman	16	15.8
Sophomore	14	13.9
Junior	24	23.8
Senior	32	31.7
Graduate	15	14.9
What is your academic major?		
Mechanical Engineering	54	53.5
Agricultural and Life Sciences Education	10	9.9
Industrial Technology	9	8.9
Agricultural Engineering	7	6.9
Agricultural Studies	7	6.9
Agricultural Education and Studies	4	4.0
Agricultural and Biosystems Engineering	4	4.0
Agricultural Systems Technology	3	3.0
Industrial and Agricultural Technology	1	1.0
Crop Production and Physiology	1	1.0
Aerospace Engineering	1	1.0

Table 2

Participant Demographics (n = 101) Continued…

Estimate the average number of hours that you spend per day playing video (e.g., computer, console, mobile, etc.) games.		
0-1 hours	71	70.3
1-2 hours	17	16.8
2-3 hours	11	10.9
3+ hours	2	1.9

The participants' welding experiences prior to engaging in our study are reported in Table 3. Most participants had not used a welding simulation / simulator system before (*f* = 79; 78.2%) and indicated they had welding experience prior to participating in our study (*f* = 70; 69.3%). Those who had welding experience prior to participating indicated they had learned to weld, and had practiced their welding skills, in a variety of settings. The participants most frequently reported prior experience in the shielded metal arc welding (SMAW; *f* = 58; 57.4%) and the GMAW (*f* = 60; 59.4%) processes. Regarding hours of experience with each process, on average participants reported they had the most hours of experience with: the (1) flux-cored arc welding (FCAW) process (*M* = 79.29, *SD* = 210.31), followed by the (2) GMAW process (*M* = 67.52, *SD* = 239.80), the (3) SMAW process (*M* = 62.54, *SD* = 242.70), the (4) gas tungsten arc welding (GTAW) process (*M* = 35.18, *SD* = 83.98), the (5) oxy-fuel welding (OFW) process (*M* = 10.19, *SD* = 9.98), and the (6) submerged arc welding (SAW) process (*M* = 0.72, *SD* = 0.41).

Table 3

Formal Study Participants' Prior Welding Experiences (n = 101)

Item	*f*	%
Have you ever used a welding simulation / simulator system (e.g., virtual reality, augmented reality, etc.) before?		
Yes	22	21.8
No	79	78.2
Have you ever welded before?		
Yes	70	69.3
No	31	30.7
If you have welded before, where have you learned how to weld?		
At my family's farm or business	24	23.8
At a farm or business not owned by my family	14	13.9
In a facility at my house (e.g., garage, workshop, etc.)	19	18.8
In my high school's Agricultural Education program	13	12.9
In my high school's Industrial Technology program	27	26.7
Other location	28	27.7
If you have welded before, where have you gotten the opportunity to weld or practice welding?		
At my family's farm or business	23	22.8
At a farm or business not owned by my family	18	17.8
In a facility at my house (e.g., garage, workshop, etc.)	21	20.8
In my high school's Agricultural Education program	14	13.9
In my high school's Industrial Technology program	26	25.7
Other location	23	22.8

Table 3

Formal Study Participants' Prior Welding Experiences (n = 101) Continued…

If you have welded before, which of the following weld processes have you performed?		
Shielded metal arc welding (SMAW; "stick welding")	58	57.4
Gas metal arc welding (GMAW; "MIG"; "wire welding")	60	59.4
Flux-cored arc welding (FCAW)	14	13.9
Submerged arc welding (SAW)	5	5.0
Oxy-fuel welding (OFW)	23	22.8
Gas tungsten arc welding (GTAW; "TIG")	27	26.7

We assumed because participants were randomly placed into one of the four protocol groups used in our study, any participants' preexisting differences, such as prior welding experiences, familiarity using welding simulation / simulator systems, and so forth, would fall within the range of anticipated statistical variation and would not confound our results.

Table 4 reported descriptive statistics for each weld process training protocol group. The mean total weld score across all four protocol groups was 74.69 with a standard deviation of 17.61. The highest mean total weld score (*M* = 80.15, *SD* = 15.07) was from participants who underwent the 100% VR welding training protocol (*n* = 26) while the lowest mean total weld score (*M* = 67.84, *SD* = 16.26) was from participants who experienced the 50% live welding / 50% VR welding training protocol (*n* = 25).

Table 4

Descriptive Statistics for Participants' Total Weld Scores by Group

							95% Confidence Interval for Mean	
Group	*n*	*M*	*SD*	*SE*	Min.	Max.	Lower	Upper
100% live welding	25	74.40	17.09	3.42	36.00	98.00	67.35	81.45
100 % VR welding	26	80.15	15.07	2.96	39.00	98.00	74.07	86.24
50% live welding / 50% VR welding	25	67.84	16.26	3.25	28.00	100.00	61.13	74.55
50% VR welding / 50% live welding	25	76.16	20.40	4.08	31.00	99.00	67.74	84.58
Total	101	74.69	17.61	1.75	28.00	100.00	71.22	78.17

Research Hypothesis: Using VR Technology to Facilitate the Development of Welding Skills to Complete 2F Tee Joints Will Result in a Significant Impact on Total Weld Scores

A Levene's test for homogeneity of variances indicated the assumption of homogeneity was met (*p* = .580). Our use of a one-way ANOVA revealed there were no statistically significant differences (*p* > .05) in total weld scores between any of the four training protocol groups, *F*(3, 97) = 2.235, *p* = .089. Effect size was calculated using Omega squared ($\omega^2 = 0.04$), which was classified as "very small" in accordance with the interpretations offered by Sawilowsky (2009, p. 599). Therefore, we rejected our research hypothesis (Table 5).

Table 5

Comparative Analysis of Total Weld Scores by Group Means

	SS	*df*	*MS*	*F*	*p*
Between Groups	2005.381	3	668.460	2.235	.089
Within Groups	29006.105	97	299.032		
Total	31011.485	100			

Note. $\omega^2 = 0.04$

Conclusions, Discussion, Recommendations, Implications, & Limitations

Our results indicated using VR technology within a one-hour-long GMAW process training session to facilitate development of welding skills to complete 2F tee joint welds did not result in a statistically significant ($p > .05$) impact on welding skill performance as determined by CWIs who used a weld evaluation rubric to determine total weld scores. As such, we concluded using VR technology as part of this process neither improved upon nor detracted from participants' total weld scores. The individuals who participated in the 100% VR welding group ($n = 26$) had the highest mean total scores for their test welds ($M = 80.15$, $SD = 15.07$). The individuals who participated in the 50% live welding / 50% VR welding group ($n = 25$) had the lowest mean scores for their test welds ($M = 67.84$, $SD = 16.26$). Perhaps the sequencing of the VR technology usage impacted performance. Researchers should examine sequencing of VR technology use in future studies. Determining a suitable time frame and method for introducing VR technology into the skill acquisition process could be impactful for skill training purposes.

We recommend our study be replicated. We do wish to emphasize both total participant quantities and group sizes should be increased to provide increased power for statistical testing. Perhaps even reducing the number of protocol groups used in future research to increase the size of each group could be beneficial. In terms of participant recruitment, the primary issue we experienced was our research site was located off-campus and may not have been easily accessible for some prospective participants, thus reducing our total number of participants. In several instances, prospective participants contacted the lead researcher directly via e-mail or text message to notify him they were unaware of the research site's off-campus location and did not have suitable transportation there. Thus, we recommend future studies be conducted at a central location easily accessible by all prospective participants.

Considering the design of our study, we were left to question if our results would have been different had the participants undergone training protocols spanning a longer time frame. Scholars (DeKeyser, 2015; Lancelot, 1944; Osborne, 1986; Wulf, 2007) have previously noted the development of skills can take time to fully materialize. Byrd (2014) used weld training protocols that were at least one week in duration is his study. It is conceivable that had we extended the duration of our training protocols to perhaps one eight-hour-long day, we may have found significant differences in total weld scores between the protocol groups. However, it is also possible that increasing the length of time individuals were asked to participate to our study may have resulted in increased subject mortality, thus introducing an internal validity issue (Campbell & Stanley, 1963). We recommend future researchers of welding skill performance carefully consider the durations of their studies and the effects of time on participants' skill acquisition processes.

We elected to focus our study on welding skill performance in the context of GMAW process training. GMAW has fewer operator variables than other welding processes and can allow for quicker skill acquisition for novice welders (Rose, Pate, Lawver, Warnick, & Dai, 2015). Further, we selected 2F tee welds due to their simplicity in comparison to other weld configurations (Stone et al., 2013). In addition, participants who were assigned to the training protocols using VR welding were not allowed to use visual cues as part of their practice sessions. Stone et al. (2013) noted using visual cues can be useful in some instances and harmful in others. As such, we question if our results would have been different had we elected to implement a different welding process such as SMAW, selected a different weld configuration, or had allowed participants to use visual cues during VR welding practice. Further research focusing on each of these variables could provide useful information relevant to welding industry stakeholders.

Considering the majority of our study's participants (*n* = 70; 69.3%) reported they had welding experience prior to participating in our study, we speculate this may have been a factor contributing to our lack of identifying statistically significant results. To help better control for this variable in future studies, we recommend researchers consider conducting experimental or quasi-experimental research with groups of novices. Large groups of novices could be found in numerous settings, including SBAE programs or university-level agricultural mechanics coursework. Moreover, if conducted within the scope of a secondary- or university-level course, future studies could examine the impacts of using VR technology over a longer timeframe, such as an entire semester or academic year, while helping to minimize participant attrition.

Regarding stakeholders, we recommend professionals involved in welding education, such as agricultural education practitioners, continue to examine how educational technology-based practices can assist in the teaching and learning of psychomotor skills. Stone et al. (2011) indicated using VR technology for weld process training purposes shows promise for preparing skilled welders. While our study did not indicate VR technology use made a statistically significant impact, follow-up research should be conducted to help determine if such technology should be considered as viable in the acquisition of welding-related psychomotor skills. Welding plays a considerable, traditional role in agricultural education, particularly at the secondary and university levels (Burris et al., 2005) and is included in many career areas in the agricultural industry. The agricultural industry is ever-changing (Doerfert, 2011) and must continue to critically examine the roles and impacts new technologies and products adoption can play (Lindner et al., 2016).

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