RECEIVED
OCT 26 2015
VP ACADEMIC SERVICES
LAS POSITAS COLLEGE

$53,000

Instructional Equipment Request
2015-16

FALL 08

already have 1;
requesting another.

SECTION 1: SUMMARY INFORMATION

Brief Title of the Request: Vertex 360 Welding Simulator

Equipment Location: 810

Name of Requestor: Scott Miner

Division/ Unit: STEMPS/WLDT

SECTION 2: EQUIPMENT DESCRIPTION

Check one of the following:
The equipment is: A replacement An upgrade [✓ New equipment/technology]

Describe the specific equipment requested and how it will be used to replace, upgrade or provide new technology to the college from what is currently in place? If there is a legal requirement, a mandate, or safety concern for purchase of this equipment, please discuss and make specific reference to that regulation/concern. (Cost data should be recorded in Sec. 7)

This a virtual reality welding training and simulation tool for welding students and educators . This tool is used to train students quicker and with greater success rates than traditional welding techniques. The VRTEX® systems are virtual reality arc welding training simulators. These computer based training systems are educational tools designed to supplement and enhance traditional welding training. They allow students to practice their welding technique in a simulated and immersive environment. The VRTEX systems promote the efficient transfer of quality welding skills and body positioning to the welding booth while reducing material waste associated with traditional welding training. The combination of realistic puddle, arc welding sound, and real time feedback tied to the welder's movement provides an exciting, hands- on training experience.
The VRTEX 360 is a best-in-class, advanced level welding training system. It
is designed to provide a full featured, expandable platform in an easy to use and engaging welding training tool. The VRTEX system is ideal for basic to advanced welding training, as a testing, recruitment and engagement tool for educational and industry and for preparation for advanced level evaluation for instructors. The VRTEX 360 is constantly on the move incorporating additions for training purposes each year.

SECTION 3: EDUCATIONAL ITEMS- PROGRAM REVIEW

Which educational programs or institutional purposes does this equipment support?

Welding & Engineering Technology

Is this equipment included in your Program Review? XXYes No

If yes, please cut and paste the appropriate wording here. If not, explain why.

Quote from program review on New Initiatives :
Virtual reality welding training equipment. Studies have shown students that train on this type of equipment prior to the actual real welding equipment, learn quicker and use less resources than traditional methods of welding skills training.

Under need for Technical resources:

Virtual reality welding training equipment. Upgrade existing welding equipment as technology needs change or equipment loses relevance.

SECTION 4: TEACHING AND LEARNING

Describe in some detail the impact this equipment will have on teaching and learning.

Impact on teaching: The VRTEX® system makes it possible to learn how to weld in an eco-friendly manner. Instructors who use virtual reality training will minimize their material waste and environmental footprint. The product teaches welding without the use of shielding gas, welding electrodes or welding coupons and does not require weld fume removal.
It also reduces the disposal of waste as a result of training such as base material, consumable parts, etc. The VRTEX® also allows students to be taught with a reduction in overall energy consumption by requiring less energy than a traditional welding machine, feeder and weld fume control system.

Impact on learning: Nothing fills seats faster than utilizing the latest technology available to train students in the classroom. The VRTEX® captures student interest and adds a new element of excitement to traditional welding training.
The VRTEX® strengthens technology-enabled learning.

- Assessment of the student's performance is based on a numerical weld score, based on AWS guidelines. This helps the student understand and learn industry recognized skills
- Hand's on learning of a skill based on the look and feel of a welding machine, but packaged in a game design. The user interface is intuitive and operates with graphical elements and sounds that engage the student.
- The VRTEX® provides immediate and continuous feedback to the student, instructor and fellow classmates. This provides the classroom to benefit from continuous improvement at the student level, but also through coaching and viewing how to adjust and correct improper techniques to achieve a good score.
- The VRTEX® allows the instructor the opportunity to adjust and change tolerances to match local industry needs or preferred instructor techniques. The instructor can customize the training software of the VRTEX® to match their course objectives.

Per academic year, this equipment will impact:
Number of classes or sections 30-40 course sections/year
Number of students 200-300 students/year (entire welding program)

SECTION 5: OUTCOMES (SLOs)

By documenting your specific SLOs, how will equipment enable student learning outcomes to be achieved? What are the consequences related to learning outcomes if request is not funded?
SLO: Pass an industry recognized welding certification test
SLO: Operate Safely in a welding workplace environment

By implementing Virtual Reality Welding training into traditional welding training programs, students learn more quickly. This increases welding school throughput and opens up more time to teach additional topics. Skilled welders cannot be trained on simulators alone and need real arc time to fine tune their welding skills; however, VR Welding Training can provide a fun and beneficial educational experience. If not funded, we will follow the traditional techniques of training welders with out simulation tools.

SECTION 6: LPC PLANNING PRIORITIES

Please address how this equipment will serve the current LPC planning priorities.

- ***Establish regular and ongoing processes to implement best practices to meet ACCJC standards***

This equipment implements best practices as understood by welding faculty with relation to training welding students. The blended learning technique has proven to be successful or using bot virtual reality and traditional welding processes

- ***Provide necessary institutional support for curriculum development and maintenance***

This equipment allows expansion and renewal of the curriculum taught in the classroom. This type of equipment has revolutionized the way welder training has occurred and will expand teaching techniques.

- ***Develop processes to facilitate ongoing meaningful assessment of SLOs and integrate assessment of SLOs into college processes***

This equipment changes the way students learn the subject matter, It directly ties to the existing SLOs in the department, and opens the doors to others.

- ***Expand tutoring services to meet demand and support student success in Basic Skills, CTE and Transfer courses.***

This equipment allows for instant feedback and evaluation of the student work, as in the past there was a lag between completion and evaluation by the student/instructor of the lab work. This equipment allows for rapid evaluation and feedback on SLOs.

SECTION 7: TOTAL COST OF OWNERSHIP (FINANCIAL & SUSTAINABILITY)

What is the potential life span of the requested equipment?: 10-15 years

What will be required to maintain the equipment, such as regular servicing or upkeep? Include these costs in initial and on-going costs below.

Little to none < $100/year

Where will the equipment be used or housed? If new storage is needed, describe the storage, location and costs to provide for it. Include these costs in initial costs below.

Welding Lab Room 810

Part A: Initial Start-up Costs	**Costs**	**Comments**
Equipment or Materials	**48,350**	**Includes upgrade 2**
Shipping or Delivery charges	**0**	
Installation costs	**0**	
Costs to modify facilities	**0**	
Vendor Discount	**0**	
Any Other Costs-training, etc.	**0**	**Specify**
Local Sales Tax	**4594**	**Included in equipment**

Grand Total Costs =	$ 52,944	Click the $ and press F9 to calculate the grand total

A completed purchase order(s) and quote(s) for this total cost must be attached.

Part B: On-going Annual Operating Costs

	Costs	
Annual service or maintenance contract	$ 0	
Estimated parts replacement each year	$ 100 or less	
Outside standardization or calibration costs	0	How often?
Storage costs	0	
New supply costs	0	

Any other costs, including labor	0	**Specify**
Annual Operating Costs =	100 or less	**How will costs be paid?**

Part C: Incremental Labor Costs
Please describe who will be the key operator and who will perform the maintenance & repairs.

Welding Instructor and Students, maintenance by existing lab technician

Are these individuals already trained? If not, how will they be trained, how long is the training and is there a cost for the training. Please include the cost above in initial start-up. Is the maintenance, operation and repair currently within their scope of duties?

Easy to learn and operate

Estimate the amount of time required in a month to perform this maintenance or operation

Less than 30 minutes

Explain how this equipment meets or exceeds basic sustainability efforts and/or provides renewable resources to the college?

The new VRTEX® virtual reality arc welding training system makes it possible to learn how to weld in an eco-friendly manner. Instructors who use virtual reality training will minimize their material waste and environmental footprint. The product teaches welding without the use of shielding gas, welding electrodes or weld coupons and does not require weld fume removal. It also reduces the disposal of waste as a result of training such as base material, consumable parts, etc. The VRTEX® also allows students to be taught with a reduction in overall energy consumption by requiring less energy than a traditional welding machine, feeder and weld fume control system. The VRTEX® will turn your welding program green.

Virtual reality welding is environmentally friendly. When properly integrated and leveraged, it can greatly reduce:

- Electrical consumption
- Base material usage
- Scrap and waste
- Welding consumable usage
- Costs associated with capturing and filtering welding fumes and gases

Funded requestors will be expected to respond to a brief RAC feedback survey by a requested deadline. Requests for computer related equipment & printers must be reviewed by LPC IT Department

IT Department Authorized Signature:______________________

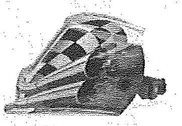
Signatures:

Requestor
Date Originated: 10/19/15

Dean/Manager
Date Received 10/21/15

Vice President
Date Received__________

Rev 05 27 15



BLENDED WELDING TRAINING

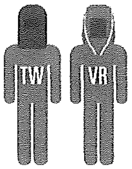
2010 IOWA STATE UNIVERSITY STUDY OVERVIEW

11

PARTICIPANTS TRAINED USING 100% TRADITIONAL WELDING

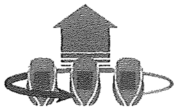
PARTICIPANTS TRAINED USING 50% TRADITIONAL & 50% VIRTUAL WELDING

22 TOTAL PARTICIPANTS



80 TRAINING HOURS OVER TWO WEEKS

THE VIRTUAL WELDING GROUP EXPERIENCED



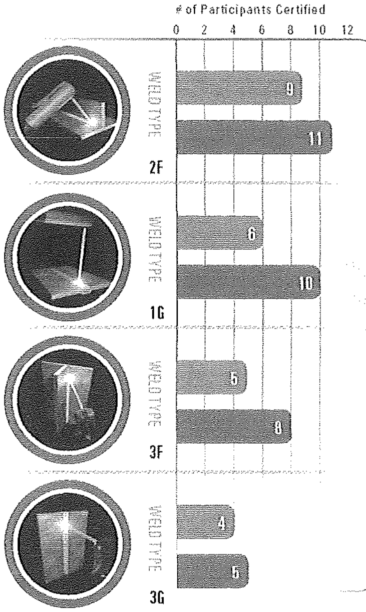
Significantly HIGHER levels of team learning and interaction

Greatly REDUCED training costs
Total savings equate to $\$2,680^{68}$ / $\$243^{69}$ per student

✓✓✓✓○○○○
✓✓✓✓✓✓✓✓

Significantly GREATER amount of welds

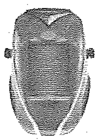
CERTIFICATION RATE



AN INCREASE OF

41.6%

IN OVERALL CERTIFICATION FOR THE VR GROUP

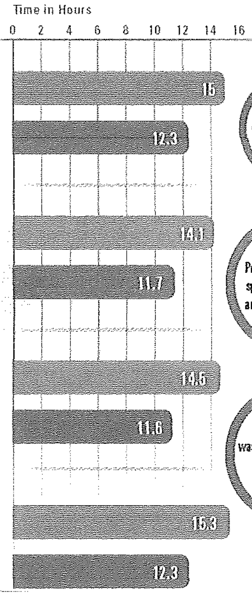


A DECREASE OF

23%

IN OVERALL TRAINING TIME FOR THE VR GROUP

TRAINING TIME



ADVANTAGES OF VIRTUAL TRAINING:

Practice welds without spending time in setup and material gathering.

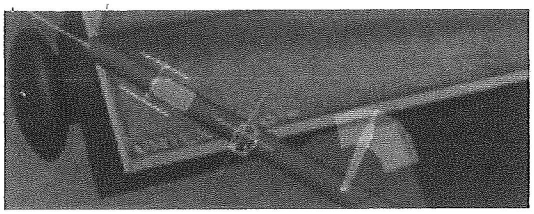
Start over without wasting material or losing time in assembly and retacking.

● 100% Traditional Welding ● 50% Traditional & 50% Virtual Welding

FOR PRODUCT INFORMATION AND TO VIEW THE STUDY, VISIT www.vrtex.com

LINCOLN ELECTRIC
THE WELDING EXPERTS®

www.vrtex.com



VRTEX® 360

VIRTUAL REALITY ARC WELDING TRAINER

BLENDED TRAINING SOLUTIONS FOR WELDING EDUCATION

The VRTEX® systems are virtual reality arc welding training simulators. These computer based training systems are educational tools designed to supplement and enhance traditional welding training. They allow students to practice their welding technique in a simulated and immersive environment. The VRTEX systems promote the efficient transfer of quality welding skills and body positioning to the welding booth while reducing material waste associated with traditional welding training. The combination of realistic puddle, arc welding sound, and real time feedback tied to the welder's movement provides an exciting, hands-on training experience.

The VRTEX 360 is a best-in-class, advanced level welding training system. It is designed to provide a full featured, expandable platform in an easy to use and engaging welding training tool. The VRTEX system is ideal for basic to advanced welding training, as a testing, recruitment and engagement tool for educational and industry and for preparation for advanced level evaluation for instructors. The VRTEX 360 is constantly on the move incorporating additions for your training purposes each year!

BENEFITS

FLEXIBILITY

- » Multiple welding processes and positions
- » Variety of joint configurations
- » Instructor tools allow modification based on preferred welding program and style

INNOVATION

- » Realistic appearance of welding puddle and welding sounds
- » Magnetic tracking system provides accurate measurements for student evaluation

CLASSROOM PERFORMANCE

- » Visual cues give real-time technique feedback
- » Record, archive and verify student work and performance

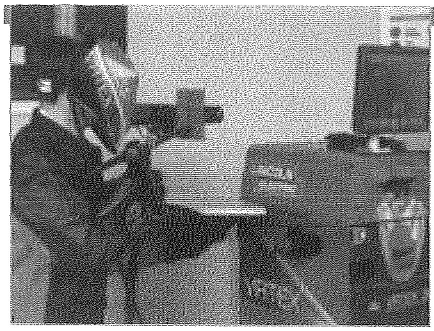
CONSUMABLE AND ENVIRONMENTAL SAVINGS

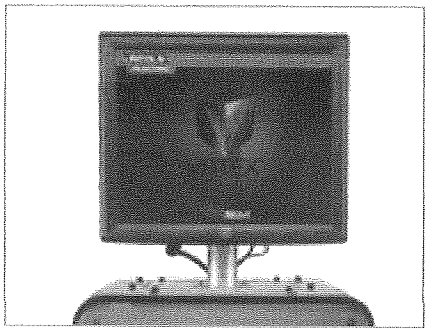
- » No welding consumables, wire or waste
- » Track savings with the *Weldometer*™

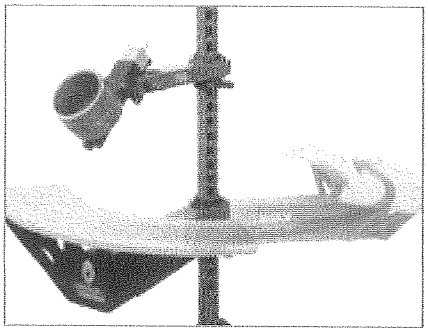
FEATURING

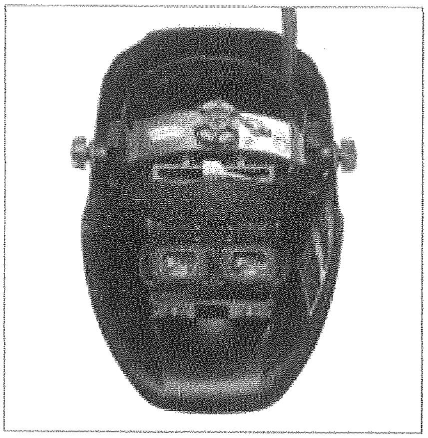
- » **Supports All Out of Position Welds** from flat, horizontal, vertical to overhead, the VRTEX 360 supports all position welding and can be ready in a matter of minutes.
- » **User Machine Interaction** provides equipment and procedural set-up using a touchscreen display for movement through the simulation software. VRTEX 360 and VRTEX Mobile supported functionality is mirrored to make transfer of interaction seamless between the systems.
- » **Dedicated Welding Gun and Stinger** provides tactile feedback which adds realism to the simulation. The VRTEX 360 stinger device retracts at the rate a real stick electrode would melt off to simulate the melting of a real electrode.
- » **Tabletop Coupon Stand** allows the VRTEX 360 welding coupons to be placed in multiple positions with or without the adjustable table to simulate real welding applications.

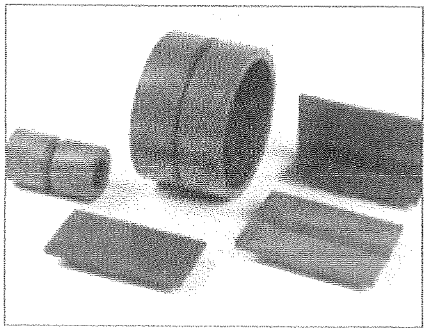
LINCOLN ELECTRIC



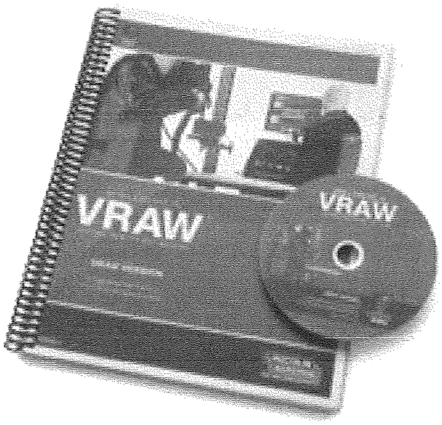








VRTEX 360 WELDING MACHINE COMPONENTS AND SPECIFICATIONS



Computer

- Windows® 7 Professional
- Intel® Core i5 Quad Processor
- 4 GB 1333 MHZ DDR3 Memory
- 60 GB Solid State Hard Drive

Software

- VRTEX welding simulation software
- THEORY Function explains and defines elements within the virtual environment
- Virtual locations: Weld Booth, Pipe Processing Plant, Desert Base, Ironworks Construction Site, Motorsports Garage (optional with Upgrade 2)

Monitor & Speakers

- 17 in. LCD Touchscreen Monitor with built-in speakers

VRTEX 360 Stand

Welding stand with independent table and arm height adjustment offers flexibility and supports multi-position welding. 90, 45 and 0 degree arm positions allow for 2G, 5G and 6G pipe welding

VRTEX 360 Stinger and Gun

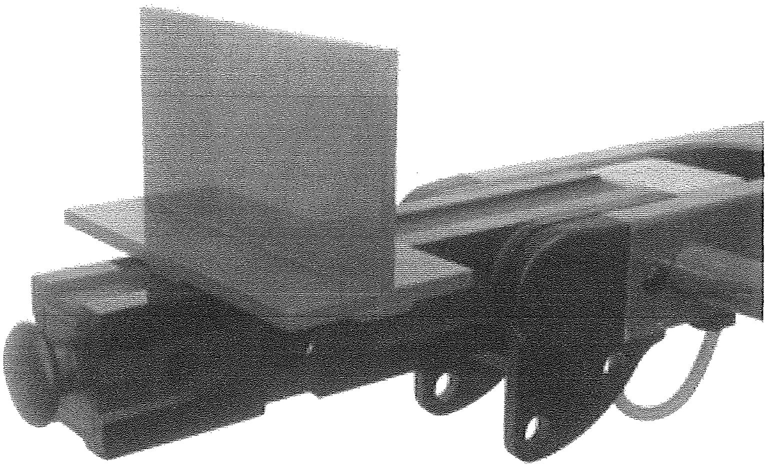
VRTEX 360 gun is based on the Magnum® 300 welding gun; VRTEX Stinger device retracts at rate of electrode melt off; Simulates SMAW, GMAW, FCAW-S and FCAW-G

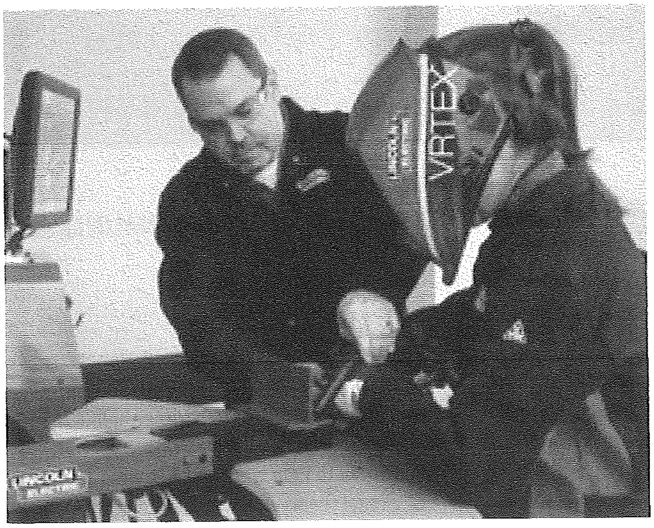
- SMAW
  - E6010 (Fleetweld® 5P+)
  - E6013 (Fleetweld 37)
  - E7018 (Excalibur® 7018 MR®)
- GMAW
  - Short Arc: SuperArc® L-56®, 0.035 in. (0.9 mm)
  - Axial Spray: SuperArc L-56, 0.045 in. (1.1 mm)
  - Pulse: SuperArc L-56, 0.045 in. (1.1 mm)
  - STT®: SuperArc L-56, 0.045 in. (1.1 mm)
- FCAW
  - Gas-Shielded: UltraCore® 71A85, 0.045 in. (1.1 mm)
  - Self-Shielded: Innershield® NR®-232, 5/64 in. (2.0 mm)

Language Support - English, French, German, Spanish, Turkish, Japanese, Chinese (Mandarin), Portuguese (Brazilian), Russian, Korean, Hindi and Arabic

Welding Coupons - Tee joint, Flat plate, Groove joint, 6 in. diameter schedule 40 pipe, 2 in. diameter XXS pipe, and Lap joint (available only with Upgrade 5)

Helmet - Monoscopic output with a large field of view





SET-UP AND INSTALLATION REQUIREMENTS:

- The VRTEX system requires a space of 8 ft. L x 8 ft. D x 8 ft. H (2.4 m x 2.4 m x 2.4 m).
- When operating multiple units in one location, alternate between standard and alternate frequency systems (unique part numbers are identified).
- The VRTEX system is not designed for operation in harsh environments. Recommendations are listed in the instruction manual.
- Avoid magnetic fields, conductive and high frequency objects and processes.
- An uninterruptable power supply (UPS) may be required for protection of the system from power irregularities and/or disruptions.

VRTEX 360 EXTENSIONS™ SOFTWARE UPGRADE PROGRAM

This upgrade program ensures the development of new and exciting features and functionality to the industry leading welding training simulator. Expand functionality, enhance instructor tools and enrich operational enhancements.

AD2435-2: VRTEX 360 Upgrade 2

- AWS virtual bend test for multi-pass pipe and groove welds and a virtual bend test certificate upon successful completion
- Advanced scoring modules based on the American Welding Society D1.1 or ASME
- Motorsports garage virtual welding environment
- Instructor panning view function

AD2435-3: VRTEX 360 Upgrade 3

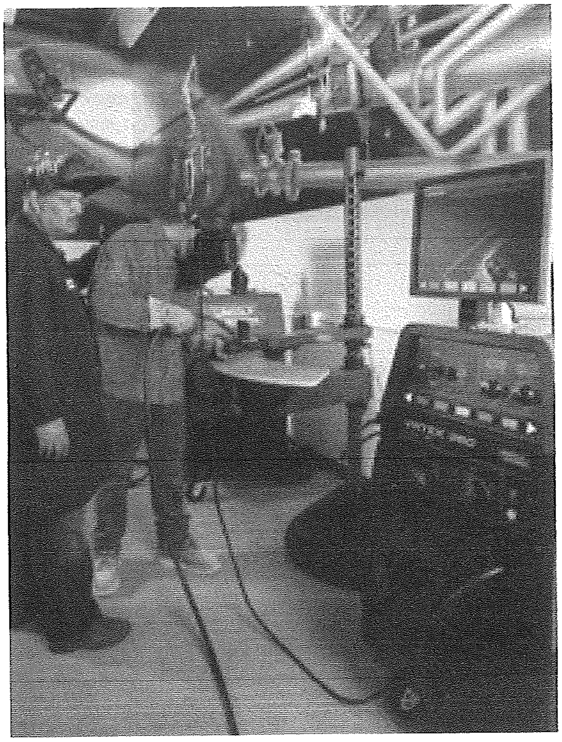
- GMAW aluminum welding support including visual and audio sound differences
- Shielding gas and THEORY additions specific to aluminum welding
- Video replay for instructor or student review and analysis on the welding process
- Entry, intermediate and advanced welder learning levels are available from the instructor view

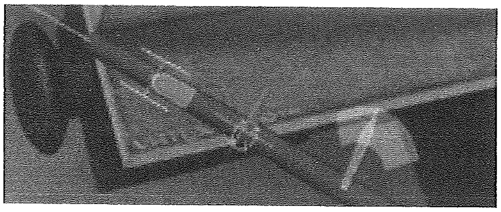
AD2435-4: VRTEX 360 Upgrade 4

- GMAW stainless welding upgrade includes multiple tolerance levels, equipment settings, discontinuities plus visual and sound differences
- Expanded THEORY functionality
- Demo Weld functionality allows the instructor or student to view an example weld or a demonstration of proper technique, prior to a weld being made
- Expanded support includes 0.052 in (1.3 mm) solid wire and SMAW on thinner material

AD2435-5: VRTEX 360 Upgrade 5

- New lap weld coupon with support for mild steel, aluminum and stainless steel
- Ability to provide a score on a welding pad to increase effectiveness and provide a numerical assessment of skill level
- Additional GMAW-P, pulse spray welding modes for use on mild steel





VRTEX® 360

VIRTUAL REALITY ARC WELDING TRAINER

VRTEX 360 Orderable Items	
VRTEX 360 System	AD2433-1 – VRTEX 360 Standard Frequency AD2433-2 – VRTEX 360 Alternate Frequency
VRTEX 360 One-Pak®	AD2434-1 – VRTEX 360 Standard Frequency One-Pak AD2434-2 – VRTEX 360 Alternate Frequency One-Pak VRTEX 360 One-Pak includes VRTEX 360 system, upgrades 2, 3, 4, 5 curriculum, project based lesson for student and instructor
VRTEX 360 New Lessons in Arc Welding	K3205-1 – SMAW Edition K3206-1 – GMAW/FCAW Edition VRTEX 360 curriculum contains spiral bound guide and DVD videos
VRTEX Project Based Lesson	K4057-1 K4058-1 Project Based Lessons for the VRTEX Welding Training Systems is a workbook containing 15 lessons that can be implemented with a welding curriculum. K4057-2 – Project Based Lessons Instructors Guide

VRTEX 360 Operating and Shipping Information	
Input Power	115/230/1/50/60
Input Current	4 A at 115, 2A at 230
Net Weight	Machine: 315 lbs (143 kg); Stand: 105 lbs (48 kg)
Dimensions (H x W x D)	Machine: 66 x 30 x 42 inches (1677 x 762 x 1067 mm) Stand: 80 x 39 x 47 inches (2032 x 991 x 1194 mm)
Packaged Weight	Crate – machine and stand: 850 lbs (386 kg)
Packaged Dimensions (H x W x D)	Crate: 72 x 48 x 72 inches (1829 x 1220 x 1829 mm)

CUSTOMER ASSISTANCE POLICY

The business of The Lincoln Electric Company is manufacturing and selling high quality welding equipment, consumables, and cutting equipment. Our challenge is to meet the needs of our customers and to exceed their expectations. On occasion, purchasers may ask Lincoln Electric for information or advice about their use of our products. Our employees respond to inquiries to the best of their ability based on information provided to them by the customers and the knowledge they may have concerning the application. Our employees, however, are not in a position to verify the information provided or to evaluate the engineering requirements for the particular weldment. Accordingly, Lincoln Electric does not warrant or guarantee or assume any liability with respect to such information or advice. Moreover, the provision of such information or advice does not create, expand, or alter any warranty on our products. Any express or implied warranty that might arise from the information or advice, including any implied warranty of merchantability or any warranty of fitness for any customers' particular purpose is specifically disclaimed.

Lincoln Electric is a responsive manufacturer, but the selection and use of specific products sold by Lincoln Electric is solely within the control of, and remains the sole responsibility of the customer. Many variables beyond the control of Lincoln Electric affect the results obtained in applying these types of fabrication methods and service requirements.

Subject to Change – This information is accurate to the best of our knowledge at the time of printing. Please refer to www.lincolnelectric.com for any updated information.

JOIN THE VRTEX COMMUNITY!

FIRST PASS

Sign up for the First Pass™ Newsletter at www.VRTEX.com:
See upcoming events, customer highlights, Lincoln Electric activity, updates and tips and tricks to help with your implementation of virtual reality welding training in your environment.

twitter.com/VRTEX
Interact with us on Twitter® and let us know how, where and when you are using your VRTEX welding training products.

facebook.com/VRTEX
Join us online and hear what others are saying. Interact and like posts and updates that you find exciting and interesting. We'd be happy to hear from you.

EXCEPTIONAL CUSTOMER SERVICE

Lincoln Electric has a global network of facilities and people to provide quick response and personalized attention. No matter where your welding operations are located today, no matter where they will be tomorrow, Lincoln Electric experts are ready to provide local support and create and implement solutions to fit your needs.

SERVICE AND SUPPORT THAT YOU CAN COUNT ON

- 24/7 Phone Support 1-888-935-3878
- Contact us with comments or questions VRTEX@lincolnelectric.com
- Online Tips and Tricks (www.VRTEX.com)
- Warranty and Service Support
- Train-the-Trainer programs held regularly in facilities or on-site training and set-up can be purchased.

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SUPPLEMENT TO THE *WELDING JOURNAL*, JUNE 2013
Sponsored by the American Welding Society and the Welding Research Council

Full Virtual Reality vs. Integrated Virtual Reality Training in Welding

A comparison is presented of the cognitive skill learning, physical skill learning, and use of training aids between the two types of training

BY R. T. STONE, E. McLAURIN, P. ZHONG, AND K. WATTS

ABSTRACT

This study demonstrates that both fully virtual and virtual reality (VR) integrated into real-world training programs are appropriate for use in the domain of welding training, depending on the level of task difficulty. Performance differences were virtually indistinguishable between participants in the fully virtual and the integrated training group at the low and medium weld difficulty levels. At the highest level of difficulty, it became apparent that the VR system was no longer solely sufficient for training. This study also tracked the usage patterns for the visual aids used in the VR simulator. These optional aids were presented to the users as overlays near the image of the weld as it was formed. Patterns observed suggest that the proper selection of certain overlays at certain stages during training was an indicator of success in both groups.

Introduction

Virtual reality (VR) has the potential to offer occupational training program developers a new tool to help meet the demands for more efficient skill training programs for hazardous environments. Developing some skills in the virtual environment allows for a reduction in material, time, and expert accessibility costs that are associated with traditional training methods. It also allows the novice to learn basic skills in a safer environment (Ref. 1). It has been suggested that VR simulators are effective at producing "pretrained novices" in that they can teach some learning aspects but not others (Refs. 2–4). However, how the design of the VR simulator influences trainee learning has only received limited attention.

A number of studies have focused on how the fidelity of VR influences training efficiency (Refs. 5, 6). Other studies have only focused on the cognitive skill learning that occurs when using simulators (Refs. 7, 8). Some work has focused on assessing the impact of an augmented reality simulator on hand-eye coordination (Ref. 9). Little work has focused on usage patterns for trainee utilization of real-time feedback features and post-task feedback.

In a previous study, we compared the results of a traditional welding training program, which involved only real-world training, with one that integrated virtual reality training using a simulator with real-world training. From this study, we learned that in the area of welding, integrating virtual reality training into a real-world training program has a number of advantages over traditional training. These advantages include increased weld quality, higher certification rates, reduced training time, improved kinesthetic skill learning, and reduced costs for the simpler welds (Refs. 10, 11).

KEYWORDS

Virtual Reality (VR)
Real-World Training
Simulator
Integrated Training
Real-Time Feedback

Follow-up Study Motivation

While conducting our previous study, we observed that before the integrated program trainees progressed to the portion of the training program where they were exposed to the real-world training, there was a significant trend of the integrated trainees achieving the preset mastery level with the VR simulator for the simpler welds. This mastery level was intended to indicate the time at which a trainee was sufficiently prepared to successfully complete the given weld. Based on these trends, it was expected that if the VR training was isolated from the real-world, the results of the integrated trainees would be similar to those of trainees who only had virtual reality training, both in terms of results and usage of the VR simulator features. However, because of the potential carryover effect from the real-world training, the validity of the preset mastery level could not be demonstrated experimentally in this prior study. Nonetheless, the observations during our previous work lead to an interest in the effect of the VR simulator features on trainee learning.

Research Goals

The goal of the present study was to first demonstrate the validity of successful training with the VR simulator. Given that validity, this study explored how trainees used the VR simulator features to learn cognitive and physical skills. These goals were addressed by comparing a fully virtual training program with an integrated training program in terms of the post-training performance of the participants. The performance was defined in terms of pass-fail weld completion rate, physical skill learning, and cognitive skill learning. For this study, the VRTEX®360 welding simulator was selected because it was capable of providing a level of realism and

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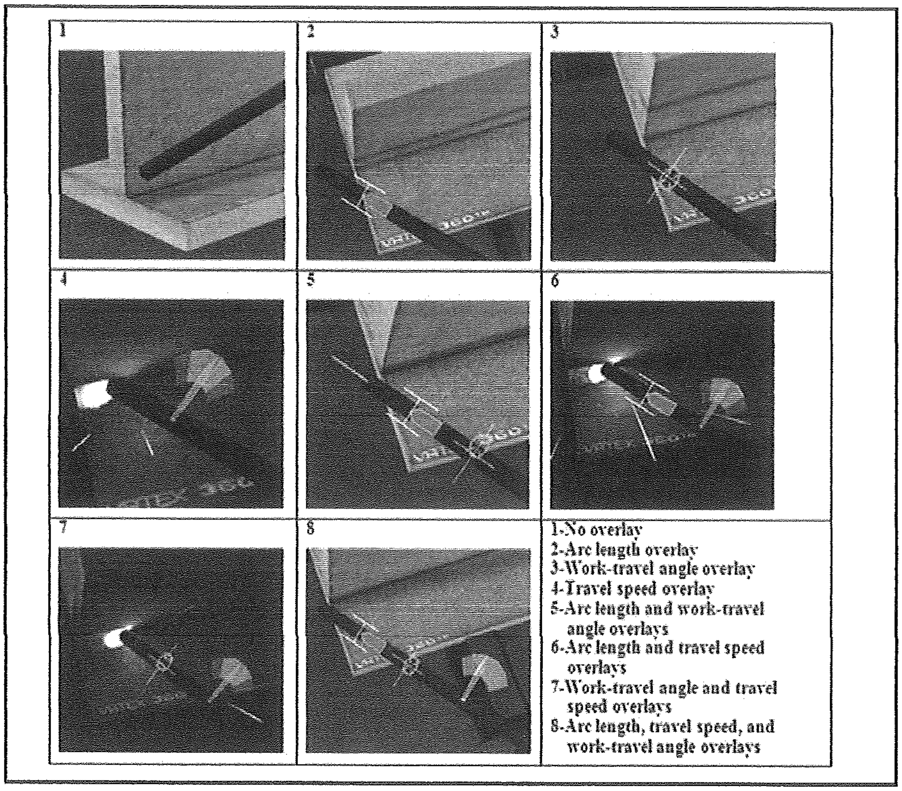

Fig. 1 — Images of possible overlay strategies (shown for a 2F weld).

kinesthetic feedback appropriate for the study. Of particular note was the availability of overlays that provided real-time visual feedback to the user. Aviation studies on visual information presented on heads-up displays in the form of overlays have shown that this method of presenting information can be absorbed and used by pilots to improve flight performance, as long as the attention needed to absorb the information presented does not exceed the available attention resource (Refs. 12, 13). For the VRTEX® 360, there were eight possible strategies for the overlay use. These eight strategies are shown in Fig. 1.

The domain of welding was selected due to the complex nature of the physical movements involved and the necessity to hone the specific physical movements for superior execution of welding tasks. According to previous real-world research in the domain of welding (Refs. 14, 15) and feedback gathered from experts, muscles that are of significant importance to welding performance include the deltoid, trapezius, extensor digitorum, and flexor carpi ulnaris. Regarding physical skill learning, it has been demonstrated that the activation and interactions of the muscles serve to distinguish between expert and novice control, ability, and stability during the commission of a task (Ref. 16). Finally, successful welding requires that the welder have a sufficient knowledge base to be able to judge variables related to creating a structurally sound weld.

For this study, it is hypothesized that 1) a fully virtual training program that is comparable to the VR component of an integrated training program will produce comparable results in terms of the kinesthetic and cognitive skills that are acquired, and 2) the selection of the type and number of real-time visual feedback indicators will be linked to the successful training of both the integrated and the VR trainees.

Table 1 — List of Overlay Strategies

Overlay Strategies and Assigned Numbers	
1	No overlay
2	Arc length overlay
3	Work-travel angle overlay
4	Travel speed overlay
5	Arc length and work-travel angle overlays
6	Arc length and travel speed overlays
7	Work-travel angle and travel speed overlays
8	Arc length, travel speed, and work-travel angle overlays

Methods

Front-End Analysis

An ethnographic study was used to define the pedagogical and technological aspects of weld training. In addition, eight expert welders were formally evaluated, particularly in terms of muscle interactions and posture, while conducting the four welds of interest in this study. These data were used to create expert models for comparison with the participants' physical skill learning.

Experimental Materials

A VR welding school and a real-world welding school were constructed on the campus of a Midwestern university. The materials stocked for the real-world school are listed in Appendix A. The VR welding school housed weld booths of the same size and dimension as their traditional counterparts. Each booth contained a new VRTEX® 360 Virtual Reality Arc Welding Trainer with SMAW attachments and multiple sets of welding jackets and gloves. This trainer was chosen due to the fact that it was the highest fidelity VR simulator currently available, and allows users to be fully immersed in a 3D VR environment while conducting welds. For the virtual training system, the user wore a weld helmet with integrated stereoscopic VR screens, used a SMAW weld attachment, of the same size and dimension as a real weld attachment, and used dynamic visual feedback, in the form of overlays, for known variables associated with welding.

Participants

There were 21 male participants randomly assigned to either the integrated training (11 participants) or the VR training (ten participants). The number of participants was initially limited in order to have a student-to-certified welding educator (CWE) ratio that was representative of real-world welding training classes, which generally do not exceed 12 people at a time. It should further be noted that all of the statistical measures utilized are appropriate for use with nonequal sample sizes.

All participants had no practical welding exposure and no experience in shielded metal arc welding (SMAW) prior to the beginning of the study. The integrated group had an average age of 41 (SD

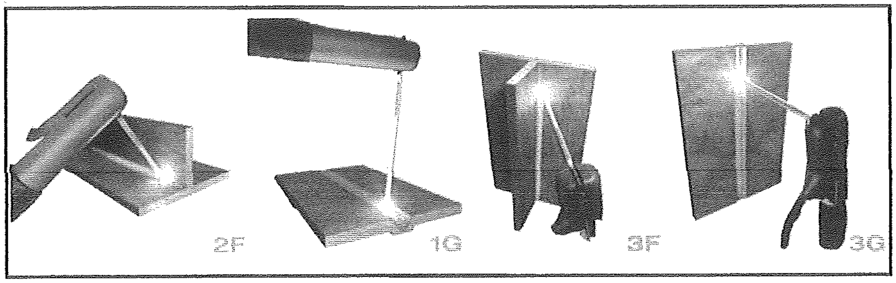

Fig. 2 — Images of weld types tested.

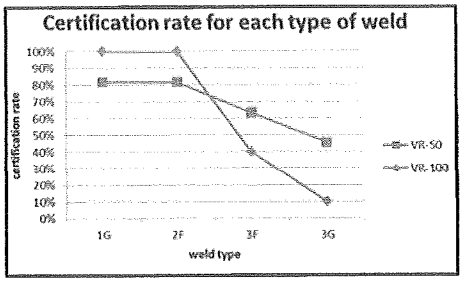

Fig. 3 — Certifications of each group from each weld type.

= 13.6) years and average height of 70.2 (SD = 2.4) in. The VR group had an average age of 41 (SD = 13.6) years and average height of 70.2 (SD = 2.4) in.

Independent and Dependent Variables

There were two independent variables in this experiment. The primary independent variable was training type with the two levels of integrated training and VR training. The second independent variable was weld type. The four weld types, in order of increasing difficulty, included the 2F (horizontal filet weld), 1G (flat groove weld), 3F (vertical filet weld), and 3G (vertical groove weld). Images of these weld types are shown in Fig. 2.

There were four dependent variables in this investigation: certification rate, physical skill learning, cognitive skill learning, and overlay usage.

Certification rates were determined based on whether or not the welds completed by the participants during the American Welding Society (AWS) welding certification tests were considered acceptable by the certification board. The quality of the welds was judged based on bend tests as well as the dimensions of the weld. For each of the weld quality tests, in addition to determining the acceptability of the weld, an overall weld quality score was assigned which ranged from 0 to 100.

In order to assess physical skill learning, electromyography (EMG) and postural observations were used. EMG data allowed the experimenters to examine the activation of the muscles of interest when participants performed the welding tasks. Further details regarding EMG instrumentation and methods are included in Appendix B. The postures adopted by participants while welding were recorded via video and direct observation by experimenters. The observations were consistent between observers.

In order to assess cognitive skill learning, a survey based on Crook's consideration of Bloom's taxonomy (Ref. 17) was used. Experimenters developed questions to measure cognitive skill learning for each weld type attempted by participants.

In addition to the previous three measures of performance, the visual overlays used for each run with the VR simulator were recorded. The overlays included in the VR welding simulator were as follows: travel speed (the appropriate horizontal speed that the welder should move the electrode holder), work angle and travel angle (the appropriate horizontal and vertical angle the welder should keep between the electrode and the weld coupon), and arc length (the appropriate distance the tip of the electrode should be from the weld coupon). While the system allowed for travel and work angle as separate overlays, a usage study conducted by the authors indicated that in all cases, participants using work and travel angle used both in equal proportion and were able to utilize them together with no performance impact; hence, for the purpose of this study, they are treated as a single overlay enhancement. As a result, there were eight different combinations of the overlays that could be used. These options are shown in Fig. 1 and described in Table 1, and will henceforth be collectively referred to as overlay strategies, and individually referred to by the assigned number.

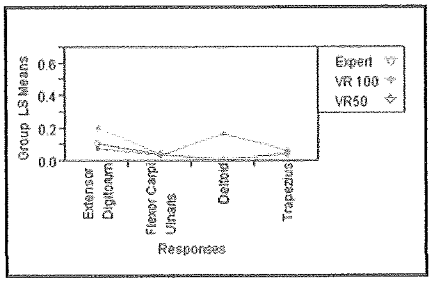

Fig. 4 — Muscle responses for 2F weld type for expert, integrated, and VR welders.

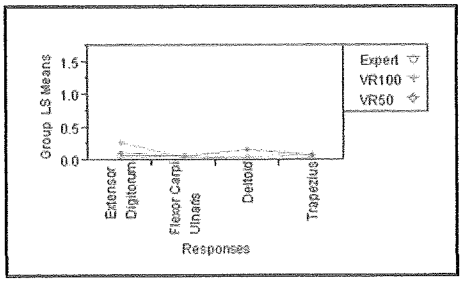

Fig. 5 — Muscle responses for 1G weld type for expert, integrated, and VR welders.

Table 2 — Data Analysis Summary for Certification Rates

	2F	1G	3F	3G
χ^2	1.053	1.053	1.818	3.810
Prob > χ^2	0.305	0.305	0.178	0.05

Table 3 — Summary of Weld Quality Data

Weld Type	2F			1G			3F			3G		
Group	Mean	S.D.	p-Value	Mean	S.D.	p-Value	Mean	S.D.	p-Value	Mean	S.D.	p-Value
VR50	92	9	0.5916	88	10	0.9248	81	16	0.2670	61	24	0.2787
VR100	89.7	3		89.5	2		71.8	19		53	19	

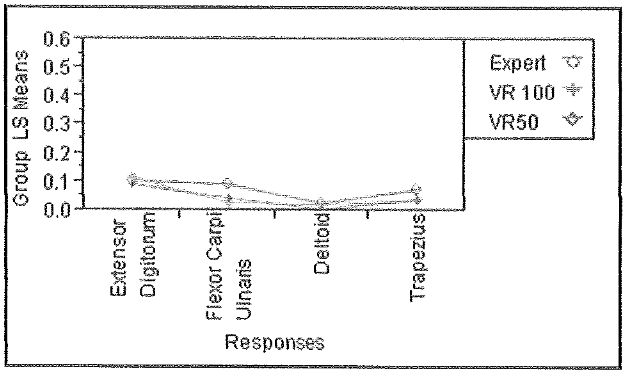

Fig. 6 — Muscle responses for 3F weld type for expert, integrated, and VR welders.

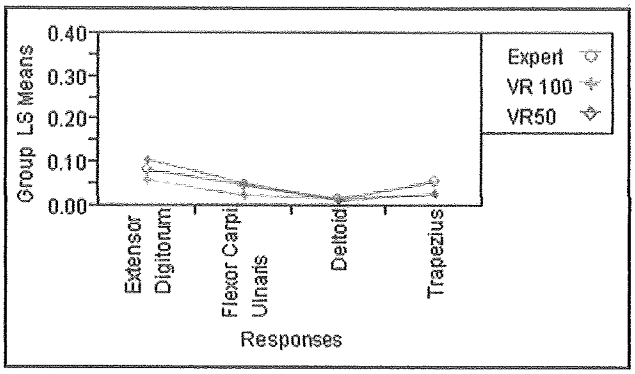

Fig. 7 — Muscle responses for 3G weld type for expert, integrated, and VR welders.

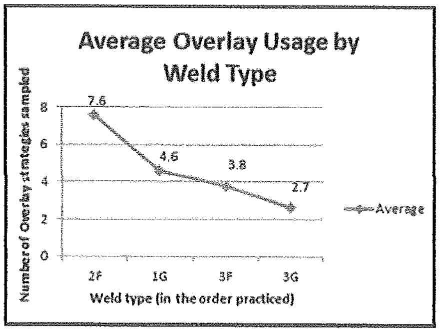

Fig. 8 — Trend of sampling as weld training progressed.

The authors specifically wanted to know how users would interact with the systems in a real-world setting. As a result, the experimental design included features that would allow them to use the system in a manner consistent with real training (for example, allowing large amounts of free practice). The experimenters noted in an earlier experiment a pattern of usage for the overlays. One of the goals of the present experiment was to see if that pattern would reemerge. To artificially force balance among conditions would not have allowed for these questions to be properly answered.

Experimental Procedure

Prior to experimentation, all participants were given informed consent followed by individual screening tests to ensure that they possessed normal visual acuity, depth perception, and hearing. Both the integrated and VR training groups were given take-home training materials and instructional videos on welding to supplement their study opportunities at home. Access to materials was regulated and no significant difference in exposure or opportunity was noted between participants by experimenters.

Also, in order to minimize the usability of the system as a factor, all participants were given training on the VR welding simulator system and system features prior to the experiments. The training ensured that all participants understood the system, the features of the system, and how to access those features. In particular, each overlay was explained in terms of its relationship to welding.

Participants in the integrated training group spent half of their time training (in pairs) with the VRTEX 360® system, and during this time, the VR system served as the instructor by providing weld quality feedback after every weld and by providing optional visual overlays that would guide the user to improve key aspects of their weld. The remaining half of their time was spent in traditional welding training under the direction of an AWS CWE/CWI® who presented lectures and supervised the participants when they practiced the weld types with real welding machines. Before changing from practic-

Table 4 — Analysis of Muscle Interactions

Weld Types	MANOVA Results	Expert vs. Integrated	Expert vs. VR	Integrated vs. VR
2F	F (8, 42) = 2.2509 P = 0.0423	F (4, 13) = 2.3230 P = 0.1114	F (4, 12) = 1.9458 P = 0.1669	F (4, 14) = 3.0576 P = 0.0526
1G	F (8, 38) = 2.6760 P = 0.0195	F (4, 12) = 5.5532 P = 0.0091	F (4, 11) = 7.6919 P = 0.0033	F (4, 12) = 1.2126 P = 0.3557
3F	F (8, 44) = 1.7561 P = 0.1122	N/A	N/A	N/A
3G	F (8, 44) = 1.2657 P = 0.2858	N/A	N/A	N/A

Table 5 — Portion of T-Test Results for Crook's Test Analysis

Crook's Consideration of Bloom's Taxonomy T-Test Values

Test Question Type Score	VR Mean Mean Score	Integrated SD	VR SD	Integrated Ratio	T	P Value
3G Knowledge	3.5	4.36	0.71	1.12	2.0868	0.0506
3G Comprehension	0.7	0.55	0.67	0.52	0.5901	0.5621
3G Application	2.1	2.36	0.32	0.67	1.1271	1.1271
3G Analysis	1.6	2.36	0.7	0.81	2.3027	0.0328

ing a given weld type with the VR welding machine to practicing with a real welding machine, the participants had to earn a simulator-generated quality score of 85% at least twice for the weld type. Once participants had moved on to the real-world training, they were not allowed to return to the virtual training. Further, they could only use as much time as they had used in the VR training for the real-world training aspect in order to keep the 50/50 split.

The participants in the VR training group spent all of their time learning in the same VR environment as did the members of the integrated group. For each weld type, participants in the VR group were allowed to practice in the VR environment for approximately the same amount of time that their integrated counterparts did. For example, the average participant in the integrated group spent 6.3 h in their VR training for the 3G weld, so the training limit for those in the VR group was set at 6.3 h with a 15% tolerance. This method ensured that the way in which the participants utilized the VR welding simulator and the VR instructional features would be directly comparable between groups.

Following the training for each weld type, participants were given their one and final weld certification test piece. They performed their prescribed test (2F, 3F, 1G, or 3G) in the presence of the CWI/CWE. Once completed, the test pieces underwent a visual inspection by the CWI/CWE on site. If the test piece passed visual inspection, it was then sent to an independent laboratory for weld quality testing. Certification or failure for the participant was based on the results of this testing. During pretest practice and the final testing plate, participants were fitted with electrodes so that experimenters could record EMG data while participants conducted their welds. The EMG data were collected during the middle phase of their welding (at this time their posture was stabilized) and averaged over 5 s (the weld usually took 30 s). Immediately following each certification test for all four weld types, participants were given a written cognitive survey related to the welding unit used and the weld type they had just performed.

Results

The performance measures for this study were weld certification rates, physical skill learning, and cognitive skill learning. Also, the relationship between the use of the visual overlay feedback and the welding performance was explored.

Certification Rate

Table 6 — ANOVA Results for Significance in Weld Types

Weld Type	F Ratio	F-Value
1G	6.9069	0.0020
2F	0.6275	0.6498
3F	11.2458	0.0001
3G	0.7102	0.5048

Table 7 — Post-Hoc Test Results for Significance in Overlay Usage

Weld Type	Overlay	Level	Mean Weld Quality	Weld Type	Overlay	Level	Mean Weld Quality
	5	A	93.8		4	A	95.0
	4	A B	92.0		5	A	93.0
	1	A B	88.3		2	A B	87.0
1G	3	B	84.7	3F	6	A B C	78.0
	8	C	74.0		8	C	64.5
					3	B C	63.0
					1	C	57.8

As summarized in Table 2, the Chi-square test found no significant difference between the two groups across all weld types except for 3G. For 3G, $\chi^2_{0.05,\,1} = 3.810$ and $p = 0.05$, indicating the integrated group had significantly more 3G certifications than the VR group. As a descriptive trend, the VR group had more certifications than the integrated group for the easier weld types (1G and 2F), while the integrated group had more certifications for the more difficult weld types (3G and 3F). The certification rates achieved by participants in the two groups for each of the four weld types are shown in Fig. 3. In addition, the mean weld quality score for both groups are shown in Table 3. No significant difference was found in quality between the two groups for any of the weld types.

Physical Skill Learning

Physical skill learning was assessed with respect to the average muscle activity expressed as a percentage of maximum voluntary contraction (MVC) for the four muscles of interest (deltoid, trapezius, extensor digitorum, and flexor carpi ulnaris muscles). The normalized muscle activities for these four muscles form a pattern of four dependent variables. A multivariate analysis of variance (MANOVA) was used to identify any interactions between the pattern formed by the experts and those of both of the experimental groups (integrated is VR 50 and VR is VR 100) for each of the weld types. Figures 4–7 show the muscle activity interaction profiles for each of the four weld types.

The results of the MANOVA for the 2F weld type show a significant difference between the expert, integrated, and VR groups. However, post-hoc MANOVA pairwise comparison tests reveal no significant difference between any two conditions. This may have been due to the decrease in the degrees of freedom. The 1G weld type MANOVA revealed that there was a significant difference between the three conditions. Post-hoc MANOVA pairwise comparison tests revealed that the integrated and VR groups did not differ from one another. However, both the integrated and VR groups were found to be significantly different from the expert group. Author observations confirmed that both the VR and the integrated group adopted an altered posture which increased body stabilization. MANOVA results of the 3F and 3G weld types showed that there was no significant difference between the three conditions. These results are summarized in Table 4.

Cognitive Skill Learning

Cognitive skill learning was measured across four categories of the Crook's consideration for Bloom's taxonomy. These categories are, in order of increasing understanding, knowledge, comprehension, application, and analysis. In order to determine if the integrated and VR groups were significantly different, it was necessary to first determine if the data were normal and had homogeneity of variance. After it was determined the two groups had homogeneity of variance and were normal, a T-test was conducted for each question type for each weld type. The results can be seen in Table 5. Each test was conducted using $\alpha = 0.05$ and 19 degrees of freedom. The results indicate only one instance of significance within the Crook's taxonomy. For the 3G analysis level, the integrated group per-

Table 8 — Dominant Usage of Overlays and Associated Participant Pass Percentages

	Overlay	1	2	3	4	5	6	7	8
2F	Number Dominant Used	8	0	2	6	5	3	0	0
	Percentage Passed	87.5	N/A	100	100	100	100	N/A	N/A
1G	Number Dominant Used	3	0	3	1	11	0	0	3
	Percentage Passed	100	N/A	100	100	100	N/A	N/A	66.7
3F	Number Dominant Used	5	1	1	1	8	1	0	4
	Percentage Passed	20	100	0	100	100	100	N/A	0
3G	Number Dominant Used	9	0	0	0	8	0	0	4
	Percentage Passed	22.2	N/A	N/A	N/A	50	N/A	N/A	0

formed significantly better than the VR group. For these T-tests, the alpha criterion was not adjusted because each level was independent and as such an adjustment such as a Bonferonni adjustment would not be applicable, even if MANOVA tests had been used to analyze the data (Refs. 18, 19, 20).

Overlay Usage

Also of interest for this study was determining if the use of the visual overlays had any impact on the performance measures. There were eight possible strategies for the overlay usage. For each of the VR welds completed by the participants, a report was generated by the system, which included a listing of any overlays used and the weld quality score. These reports were used to identify and analyze any patterns in terms of overlay usage strategy and weld quality.

It was first determined if the integrated group used the overlays during their VR training differently than the VR group. For each of the four weld types, a series of T-tests was performed to compare the percentage of usage for each of the overlay strategies for the two groups (VR and integrated). It should be noted that the alpha criterion was adjusted using the Bonferroni method. The results of these T-tests indicated the two groups were not significantly different in their use of the overlays. As a result, for the following analyses, the data for the two groups could be combined. An ANOVA was used to determine if the use of any of the overlay strategies during the welding training had a significant impact on the weld quality score for the real-world test welds submitted for certification. This test indicated that the weld quality of the 1G and the 3F weld type were significantly impacted by the choice of overlay strategy. The results are shown in Table 6.

Next, Tukey post-hoc test was conducted using the T distribution at $\alpha = 0.05$ to determine which overlay(s) were significant and if they produced more or lesser quality welds. The results for this test are shown in Table 7. For both the 1G and 3F weld types, overlay strategies 4 and 5 produced high mean weld quality scores (high is >90), while overlay strategies 1, 3, and 8 produced low mean weld quality scores (low is <90).

However, examining the quality scores in isolation presents an incomplete picture. The dominant overlay strategy used for each participant for each weld type needs to be considered. Examining thesedata in conjunction with the pass rate will allow for greater transparency of what overlay strategy was the most successful for producing passing welds. Table 8 shows the dominate strategy by weld type as well as the percentage of people who used that overlay type who passed their weld. By examining Table 8, and keeping in mind the previously determined information that overlays 4 and 5 were the most successful overlays, it can observed that for the two significant trials (1G and 3F), overlay 5 was much more widely used. As a result, it can be concluded that overlay 5 was the most widely used and successful strategy.

Another trend observed was a decrease in the sampling of overlay strategies as the participants practiced more difficult weld types. Figure 8 shows the number of overlay strategies sampled as the participants progressed through the VR welding training.

Discussion

For the comparison of performance measures between integrated and VR welding training, it was hypothesized that 1) a fully virtual training program that is comparable to the VR component of an integrated training program will produce comparable results in terms of the kinesthetic and cognitive skills that are acquired, and 2) the selection of the type and number of real-time visual feedback indicators will be linked to the successful training of both the integrated and the VR trainees. A discussion of the results of this study in light of these hypotheses follows for each of the weld types.

2F Weld Type

The 2F weld type was the simplest type of weld to complete for this study. The analysis of the certifications obtained by participants in both groups revealed no significant difference. This indicated that for the simplest weld, the VR training was overall as effective as the real-world training. Since there was no interaction of the muscle activity patterns for the VR and integrated groups when compared to the experts, interfacing with the physical VR simulator tools was sufficient to develop similar physical skills, in terms of motor control, as experts. The results also showed that the reference materials that the VR group had access to (welding CD, welding texts, and information presented through the VR simulator interface) were sufficient to produce equivalent cognitive skill learning as what the integrated group gained with the welding lectures and the real-world welding exposure.

1G Weld Type

The 1G weld type was a medium difficulty weld. The analysis of the certifications obtained by participants in both groups revealed no significant difference. This indicated that for this medium difficulty weld, the VR training was overall as effective as the real-world training. The results showed that the reference materials that the VR group had access to were sufficient to produce equivalent cognitive skill learning to what the integrated group gained with the welding lectures and the real-world welding exposure.

There was a significant difference in the muscle activity patterns for the VR and integrated groups as compared to the experts, indicating that interfacing with the physical VR simulator tools did not develop the same physical skills, in terms of motor control, as experts. However, these differences exist because both the VR and integrated groups adopted the same, more stable posture for completing the weld. It should be noted that, although the integrated group completed real-world welding after the VR training, the real-world training did not change the pattern of using this alternate posture for completing the 1G weld.

3F Weld Type

The 3F weld type was also a medium difficulty weld. The analysis of the certifications obtained by participants in both groups revealed no significant difference. This indicated that for this medium difficulty weld, the VR training was overall as effective as the real-world training. Also, since there was no difference in the muscle activity patterns for the VR and integrated groups as compared to the experts, interfacing with the physical VR simulator tools was sufficient to develop similar physical skills, in terms of motor control, as experts. The results showed that the reference materials that the VR group had access to were sufficient to produce equivalent cognitive skill learning to what the integrated group gained with the welding lectures and the real-world welding exposure.

3G Weld Type

The 3G weld type was the most complex weld to complete for this study. The analysis of the certifications obtained by participants in both groups did reveal a significant difference, with fewer certifications for the VR group. This information indicates that the VR training was not sufficient for training the participants in how to correctly complete this complex weld. The integrated group had a higher certification rate than the VR group, indicating that the fidelity of the VR simulator played a role in the decreased efficiency of the training. Also, although the integrated group had a higher certification rate than the VR group, the number of certifications earned by the integrated group for the 3G weld was significantly less than the number earned for the other three weld types, indicating that the amount of real-world training time also played a role in the effectiveness of the training.

Also, there was a significant difference in the cognitive skill learning, with the integrated group having more understanding for analysis, the highest level of development. These results suggests that to have a more complete understanding of the more complex welds, the VR simulator is not sufficient. However, since there was no difference in the muscle activities for the VR and integrated as compared to the experts, interfacing with the physical VR simulator tools was sufficient to develop similar physical skills, in terms of motor control, as experts.

Overlay Strategies

Regarding the relationship between the strategic use of the visual overlay feedback and the welding performance, it was observed that some overlay strategies led to better quality scores than others. The overlay strategies that consistently led to higher quality scores were 4 and 5. The overlay strategies that consistently led to lower quality scores were 8, 3, and 1. Furthermore, it was concluded that overlay 5 was the most widely used and successful strategy.

The trend indicated by these results shows that as the complexity of the weld increased, the participants who used more overlays, and thus increased the amount of feedback, tended to have improved performance. This general strategy has been shown to be successful in other studies (Ref. 21), up to a point. As participants continued to increase complexity, it was expected that they would reach a "tipping point" where performance no longer increased, but rather decreased. This effect was observed in this study and the tipping point was three overlays.

In addition, selecting an appropriate overlay strategy was most important for the medium difficulty welds. For the simplest weld, the overlays were not particularly necessary. For the complex weld, the selection of the overlays became less relevant because the fidelity of the VR simulator in accurately representing the welding conditions was limited. The trend observed for the sampling of the overlay strategies reflects this distinction. For the simplest weld, the sampling was increased because no strategy was truly more effective than the others; however, the participants were just beginning the VR training so they were more likely to explore the different options available. For the most complex weld, the sampling was greatly diminished because again no strategy was truly more effective than the other; however, the participants were now accustomed to the VR simulator and thus had no motivation to try other overlay strategies.

Conclusions

The results of this study have shown that VR and integrated training programs are both appropriate for use in the domain of weld training depending on the level of task difficulty. The differences between the VR and integrated groups were virtually indistinguishable at the low- and medium-weld difficulty levels. It was only at the highest level of difficulty that it became apparent that the VR system was no longer sufficient and required supplementation from real-world training. It is important to point out that the visual overlay usage in both groups followed similar trends. Both groups showed a trend of decreased sampling as the training progressed.

The worst welders tended to be more erratic in their selection and often would attempt to utilize too many overlay features (such as using travel speed, work-travel angle, and arc length) at the same time. Utilizing this many overlays at once resulted in participants no longer being able to give sufficient amounts of their visual attention resource to the actual weld bead being created. Hence, these individuals failed to properly transfer skills when placed in real-world environments.

The results of this study have demonstrated the advantages and limitations of fully virtual and integrated training in terms of feedback usage, performance, cognitive skill, and physical skill learning.

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Appendix A

List of Materials for Real-World Welding School

1) Lincoln Electric Power MIG 350MP welding machine with SMAW (shielded metal arc welding) attachments
2) Two auto darkening welding helmets
3) Multiple sets of welding jackets and gloves
4) Power grinders
5) Slag hammer
6) Wire brushes
7) Welding table
8) Quenching buckets
9) Flat stock plates
10) Groove plates
11) 7018 electrodes
12) Runoff tabs
13) Consumables

Appendix B

Notes Regarding Collection of EMG Data

To collect EMG data, equipment by FlexComp Infiniti Cl. by Thought Technology Ltd. was used. The sample rate was 2048 samples/s. The sensor used was EMG MyoScan-Pro Sensor, and the electrode was T3402M-Triode by the same company. The EMG feedback signal was filtered, rectified, and smoothed automatically by the software packaged with the FlexComp Infiniti Cl hardware.

Maximum voluntary contractions (MVC) were performed in order to obtain a baseline for the maximum the participants were willing to exert their muscles. For the MVC for the trapezius and deltoid, the participants abducted their arms at the shoulder joint in the coronal plane at 90 deg against a stationary force. For the MVC for the extensor digitorum, the participants were asked to perform an extension of the wrist against a stationary object while the they held their extended arm (abducted about the shoulder in the sagittal plane) horizontally in front of them. Finally, for the MVC of the flexor carpiularis, the participants was asked to squeeze a handle in order to achieve a power grip. This was achieved while the participant's extended arm (abducted about the shoulder in the sagittal plane) was held horizontally in front of them.

Virtual Reality Integrated Welder Training

A scientific evaluation was performed of training potential, cost effectiveness, and implication for effective team learning

BY R. T. STONE, K. WATTS, AND P. ZHONG

ABSTRACT

Training in the welding industry is a critical and often costly endeavor; this study examines the training potential, team learning, material consumption, and cost implications of using integrated virtual reality technology as a major part of welder training. In this study, 22 participants were trained using one of two separate methods (traditional training (TT) and virtual reality integrated training (VRI)). The results demonstrated that students trained using 50% virtual reality had training outcomes that surpassed those of traditionally trained students across four distinctive weld qualifications (2F, 1G, 3F, 3G). In addition, the VRI group demonstrated significantly higher levels of team interaction, which led to increased team-based learning. Lastly, the material cost impact of the VRI group was significantly less than that of the TT group even though both schools operated over a full two-week period.

Introduction

Welding is a skill, and as such requires that its practitioners be trained to a standard; this kind of training requires time, money, and talent. For nearly as long as modern welding has existed, innovators have been exploring new ways to increase the effectiveness of its training.

Currently, computer-based virtual reality (VR) training (CS Wave) and immersive VR training systems (VRTEX™, ARC+) have generated interest because they have the potential to reduce training costs (Refs. 1–3). However, cost savings is only beneficial if the result is a competent welder who is trained in a timely manner.

Prior to this study, the direct training impact of using VR technology as an integrated part of weld training has not been evaluated. Published works pertaining to VR technology in welding focus primarily on the training technology and its development, not the development of the trainee (Refs. 4, 2). Many studies have focused on general use of VR in training operations and results are far from conclusive. Some studies have shown that the use of VR technology leads to reduced learning and transfer of skills (e.g., Refs. 5, 6). Other studies have shown that the use of VR technologies in training is not significantly different from real-world training (e.g., Refs. 7, 8). Many studies have found that the use of VR technologies leads to a superior transfer of skills when compared to traditional methods (Refs. 9–12). There are many reasons for this diversity of findings, like the methodology used for investigating the transfer of training (Ref. 13). More commonly, however, it is the fidelity of the different VR machines evaluated and the degree to which the individual technologies were suited to their tasks that account for the major sources of inter-study variation (Refs. 14, 15).

Modern technology has evolved to a point such that some VR systems have the ability to create high-fidelity immersive environments (due in large part to advanced physic engines and graphics-rendering capabilities) coupled with an ability to achieve realistic kinesthetic movements (due to magnetic displacement technologies allowing for 6 depth-of-field movements). These aspects of current VR welding simulators allow users to utilize kinesthetic and cognitive learning in a way never before available in the virtual environment. In addition, some VR systems such as the VRTEX™ 360 allow users to work in teams, with one member observing welding progress while the other conducts the actual VR welds. This kind of system further encourages team-based interaction and learning among users. It must be noted that the authors hold the VRTEX 360 as an example of a VR system capable of providing a level of realism and kinesthetic feedback appropriate for this study. The authors do not endorse this product over others that have the before-mentioned capabilities.

Prior to conducting this investigation, the authors hypothesized the following: 1) VR integrated training would result in superior training outcomes when compared to traditional methods, 2) the use of a state-of-the-art VR system would lead to increased levels of team interaction and learning, and 3) weld training conducted with VR integrated technology would be significantly less expensive than training conducted using traditional means.

KEYWORDS

Virtual Reality
Welder Training
Human Factors
Shielded Metal Arc Welding

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Background

Transfer of Training Paradigm

The simplest way to evaluate the amount of learning that has taken place during the course of a training program is to measure performance prior to training and compare it with performance measures after training has taken place (Ref. 16). Often, training performance is measured in terms of both operation completion time and accuracy. These measures can be translated into training effectiveness ratios (TER) that enable comparison between training conditions.

The transfer of training paradigm requires a minimum of two groups of trainees, functioning as an experimental group and a control group (Ref. 17). The group(s) given a new instructional device (or alternative method of training) is the experimental group(s). The group given the standard training (or no training) is the control group. In this experiment, the experimental group used VR training technology 50% of the time and traditional training the remainder of the time (VRI), whereas the control group used traditional means of training 100% of the time (TT). To employ the transfer of training paradigm effectively, it is necessary to select appropriate

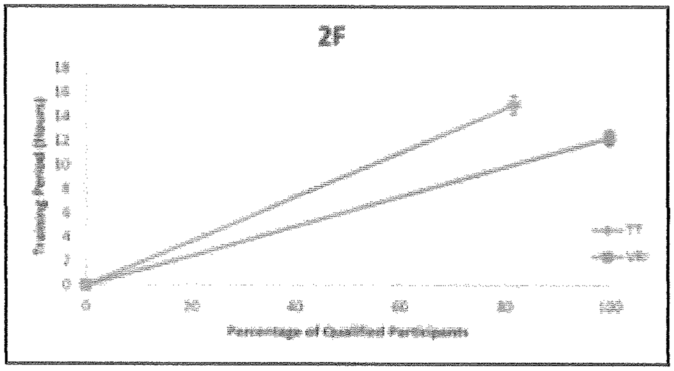

Fig. 1 — Training performance and time outcomes for training in the 2F position.

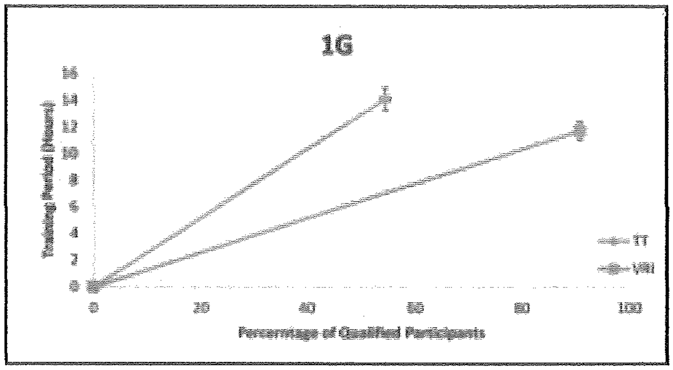

Fig. 2 — The four certifiable weld positions in this study, depicted in order of increasing difficulty.

measurements to determine the extent to which training has been effective. In the case of this study, the qualification rate (the number of welders qualified for a specific position) was used as the primary performance measure. The performance of the control group, measured in terms of time and qualification rate, was used as a baseline. A positive transfer effect occurs when the experimental group performs as well as or better than the control group. In the transfer of training paradigm, the control group is automatically assigned a TER of zero. A TER greater than zero represents a positive transfer effect; while a TER less than zero indicates a negative transfer effect. The percent transfer is the absolute difference between control and experimental group performance. The transfer of training paradigm is an effective tool in the assessment of alternative training methods, and has commonly been used to determine the transfer effect between virtual reality, augmented reality, and real training environments (e.g., Refs. 15, 18–20) particularly in laparoscopic surgery (e.g., Refs. 21, 22) as well as in aircraft simulation (Refs. 23, 24).

Team Interaction and Learning

Team learning occurs when multiple individuals carry out activities that enhance the acquisition and development of competencies in all team members. Research has shown that students who learn in team situations have a stronger tendency to learn from past experiences and are more likely to take actions that lead to continuous development (Ref. 25). This has been documented many times in various settings including many college classrooms (Refs. 26, 27). In this study, the team learning questionnaire (TLQ) that was developed and validated by Breso et al. in 2008 formed the basis for our team learning evaluation (Ref. 28). The TLQ evaluation was modified so that the questions and content were specific to the domain of weld training. The TLQ method of evaluation tracked three key dimensions of team learning and interaction that were relevant to this study: 1) Continuous Improvement Seeking (the degree to which a team can learn from previous experiences); 2) Dialogue Promotion and Open Communication (the degree to which open and honest communication is encouraged and takes place within a team); and 3) Collaborative Learning (the degree to which team members are seen and used as sources of knowledge by the rest of the team). Each dimension consists of a series of questions, which the participant answers on a five-point scale (the higher the rating for a given question the more positive the participant feels about the team learning for that question). In addition to TLQ, the authors of this study used continuous video and auditory recordings to assess the amount of time students spent interacting within the weld booths.

Experiment

Training Facilities and Equipment

Both a traditional and a VR welding facility were constructed on the Iowa State University campus. The traditional facility housed six welding booths. Each booth was equipped with the following: a new Lincoln Electric Power MIG 350MP welding machine with shielded metal arc welding (SMAW) attachments, two autodarkening welding helmets, multiple sets of welding jackets and gloves, power grinders, slag hammer, wire brushes, welding table, quenching buckets, and other miscellaneous welding equipment. The welding facility was stocked with an ample supply of runoff tabs, flat stock plates, groove plates, and 7018 electrodes.

The VR weld training facility was located one floor below the traditional facility and housed weld booths of the same size and dimensions as their traditional counterparts. Each booth contained a new VR welding trainer with SMAW attachments and multiple sets of welding jackets and gloves. The VRTEX 360 trainer was chosen because it is the highest fidelity VR simulator currently available, and has design features that the authors felt would greatly affect team-based learning.

Certified Welding Inspector

Achieving the rank of AWS Certified Welding Inspector (CWI) represents a base standard for instructor capability; as such, the CWI capability was considered to be a controlled variable. However, it is important to note that individual teaching styles and capabilities are an important influencing factor in knowledge acquisition. For this reason, the experimenters observed four different CWIs at three different welding schools so as to learn what individual differences existed between them. Analysis revealed that the major factor was overall experience in teaching (how long they have been instructing). For this reason, the experimental protocol of this study called for a CWI with at least 15 years of active teaching experience.

There was one paid CWI (who had 15 plus years of experience) used in this experiment to train participants in both the TT and VRI groups. All CWI activities were closely monitored by the experimenter to ensure that the same style of interaction and information exchange was maintained between the CWI and participants in both groups. Lastly, poststudy questionnaires sent to participants revealed that participants in the TW group rated their instructor's capabilities as a teacher at 4.2/5, participants in the VRI group rated their instructors as 3.8/5. This indicated that the perception of the instruction between the two groups was not significantly different. The controls for the CWI were appropriate; if an alternative CWI with similar experience were to have been used the overall outcome would be expected to remain the same.

Participants

There were 22 participants in total (21

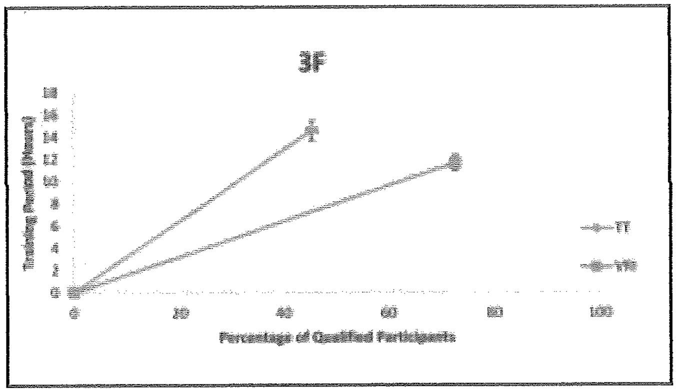

Fig. 3 — Number of certifications awarded by weld type (in order of increasing difficulty).

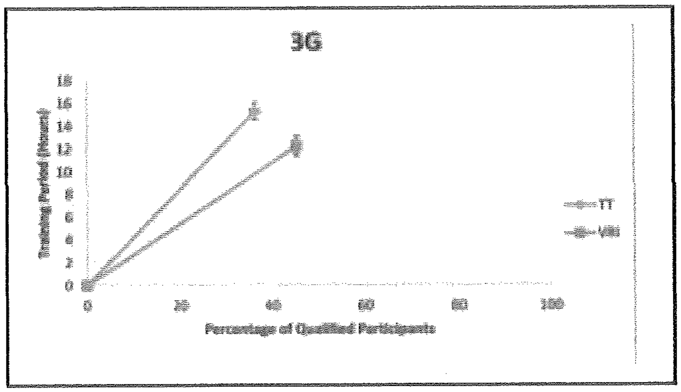

Fig. 4 — Mean training times by weld type (in order of increasing difficulty).

males and one female). All participants committed to 80 training hours over the course of two weeks. Participants were randomly assigned to one of two groups. Group one (VRI) subjects were trained with 50% VR + 50% traditional training, whereas group two (TT) subjects were trained using only the traditional training system. Participants in this study were screened to ensure little to no welding experience prior to the beginning of this study. The four participants with some previous experience were evenly distributed between the two experimental groups. Participants in the TT and VRI groups had an average age of 44 and 41 years, respectively.

Independent and Dependent Variables

The primary independent variable in this experiment was training type at two levels, representing the type of interface tested: Traditional Weld Training (TT) and 50% Virtual Reality Training (VRI).

There were five major dependent measures in this investigation: percentage transfer, training effectiveness ratio (TER), team learning, material consumption, and cost effectiveness. Percentage transfer and TER are both training potential measures. As such, both were based on the outcomes of participant qualification rates and training time. Qualification rates were evaluated for each of four different weld positions tested in this study, including the 2F, 1G, 3F, and 3G positions. Training time was defined as the total amount of time taken to train for a qualification. Team learning was measured using the TLQ questioner and follow-up video evaluation. Material consumption and cost effectiveness were functions of total plate and electrodes.

Experimental Procedure

Prior to experimentation, all participants gave informed consent, followed by individual screening tests to ensure that they possessed normal visual acuity, depth perception, and hearing. Upon completion of screening tests participants were randomly assigned to either the VRI or the TT experimental group. The TT group trained at ISU for two weeks, and then one week later the VRI group trained for two weeks.

In the traditional welding school (TT group), participants were trained in the principles and practical application of welding techniques starting with the simplest position (2F), and proceeding through to the most difficult (3G). The maximum amount of training time allotted for teaching was fixed; this time included formal lectures and practical lab training conducted by an AWS Certified Welding Inspector (CWI). The CWI was responsible for evaluating welds to determine whether or not a participant was ready to be tested prior to the end of his or her total allotted training time. Following the training for each qualification, participants were given their test plate. If the test plate for the qualification test passed the CWI's visual inspection, it was sent to an independent laboratory for structural testing. Qualification for certification was based on the results of this structural testing. Immediately following the qualification tests for all four welds, participants were administered TQL evaluations.

In the VR integrated welding school (VRI), the experiment was conducted in the same basic manner as the previous group. Both TT and VRI groups were given the same overall training time opportunity for each weld type. The major difference between traditional training and VR integrated training was in the training system itself. Participants in the VRI group spent only 50% of their time training (lectures and practical lab training) under the direction of an AWS CWI for each weld type. The remaining 50% of their time was spent training on the VR system. During VR training time, the participants (in pairs) used the VR system to conduct virtual welds of each of the four weld types on which they would be tested. If the participants were able to earn a machine-generated quality score of 85% at least twice in a row for a weld, they were permitted to discontinue their VR training time early.

Results

Training Potential

Training potential is defined by both the percent transfer and the transfer effectiveness ratio (TER). These measures encompass both the differences in certification outcomes between the groups as well as the differences in absolute training time between the groups.

Figure 1 shows the training differences in terms of qualification rate and training time for the 2F position. Participants in the VR50 group (q. rate = 100%, M time = 12.27 h) outperformed the TW (q. rate = 81.8%, M time = 15.05 h) group in terms of both qualification rate and training time. The VRI group was found to have a 22.2% positive transfer and a TER of 1.81 when compared to the TT group.

Figure 2 shows the training differences in terms of qualification rate and training time for the 1G position. Participants in the VRI group (q. rate = 90.1%, M time = 11.72 h) outperformed the TT (q. rate = 54.5%, M time = 14.09 h) group in terms of both qualification rate and training time. The VRI group was found to have a 66.7% positive transfer and a TER of 5.68 when compared to the TT group.

Figure 3 shows the training differences in terms of qualification rate and training time for the 3F position. Participants in the VRI group (q. rate = 72.7%, M time = 11.60 h) outperformed the TT (q. rate = 45.5%, M time = 14.54 h) group in terms of both qualification rate and training time. The VR50 group was found to have a 60% positive transfer and a TER of 5.17 when compared to the TW group.

Figure 4 shows the training differences in terms of qualification rate and training time for the 3G position. Participants in the VRI group (q. rate = 45.5%, M time = 12.25 h) outperformed the TT group (q. rate = 36.4%, M time = 15.31 h) in terms of both qualification rate and training time. The VRI group was found to have a 25% positive transfer and a TER of 2.04 when compared to the TT group.

Team Interaction and Learning

Team interaction and learning was assessed across three dimensions [1) Continuous Improvement Seeking, 2) Dialogue Promotion and Open Communication, and 3) Collaborative Learning], each representing a different aspect of cognitive capability. Interaction styles were evaluated using video-based interaction analysis.

The VRI (M score = 4.47) group was not found to be significantly distinctive from the TT (M score = 4.14) group in terms of continuous improvement seeking ($T_{0.05,\,1,\,20} = -1.617$, $P = 0.121$). Hence, both groups demonstrated a very strong desire to learn from their experiences and to use what they learned to improve as individuals and as a team. This finding indicates that the participants in both groups were equally willing to learn in the team context.

The VRI (M score = 4.63) group was found to be significantly more developed in terms of Dialogue Promotion and Open Communication than was the TT group (M score = 3.85) ($T_{0.05,\,1,\,20} = -4.542$, $P < 0.001$). Students in the VRI group were significantly more likely to engage in task-specific communication with their team member than were students in the TT group. Video analysis revealed that the VRI group spent an average of 32% of their shared-booth virtual reality training time engaged in training-relevant discussion (this discussion was primarily related to the screen-observing student directing the student performing a virtual weld). This can be compared to only 17% of the time spent in training-related discussion when sharing a booth in the real world training facility (this discussion occurred primarily when the team member was in between passes). Video analysis demonstrated that participants in the TT group engaged in training-relevant discussion an average of 10% of the time when sharing a booth in the real-world training facility (this discussion occurred when the team member had completed a pass or a full plate).

The VRI (M score = 4.73) group was found to be significantly more developed in terms of Collaborative Learning than was the TT group (M score = 3.30) ($T_{0.05,\,1,\,20} = -8.318$, $P < 0.001$). Students in the VRI viewed their team members as sources of knowledge to a greater extent than did students in the TT group. The higher the level of collaborative learning in a team the greater the likelihood that positive teamwork interaction took place and they learned from one another.

Material Consumption

Real-World Material Usage

The VRI group used significantly less flat plates than the TT group ($T_{0.05,\,1,\,20} = 4.607$, $P < 0.001$). The VRI group used 210 flat plates compared to the TT group, which used 288.

Also, the VRI group used significantly less groove plates than did the TT group. The VRI group used 50 groove plates compared to 63 for the TT group ($T_{0.05,\,1,\,20} = 2.711$, $P = 0.013$). Similarly, the VRI group used significantly less electrodes than did the TT group, 111.2 lb for the VRI group compared to 187.6 lb for the TT group ($T_{0.05,\,1,\,20} = 8.958$, $P < 0.001$).

Virtual-World Stock Material Usage

The VRI group used a significantly larger amount of overall flat plates (when considering both virtual- and real-world plates) than the TT group. The VRI group used a total of 550 combined (real + virtual) flat plates compared to the 288 real plates the TT group used ($T_{0.05,\,1,\,20} = -12.343$, $P < 0.001$). The VRI group used a significantly larger amount of overall groove plates than did the TT group. The VRI group used a total of 82 combined plates compared to the 63 real plates the TT group used ($T_{0.05,\,1,\,20} = -8.542$, $P < 0.001$). However, the VRI group did not use a significantly larger number of electrodes than did the TT group. The VRI group used 205.2 lb of electrode vs. 187.6 lb used by the TT group ($T_{0.05,\,1,\,20} = -1.386$, $P = 0.181$). The increased plate use in the VRI group reflects the fact that these students were able to conduct more overall welds due to the fact the virtual environment allows for focused welding time without the need for setup, tacking, etc. No difference in electrode usage was discovered primarily because the VR environment does not suffer from sticking and associated electrode abandonment, as does the real-world condition.

Material Costing

The material costs in this study reflect the consumables purchase prices; it must be noted that these prices may vary depending on a company's vendor and purchasing agreements. Additionally, prices reported in this study do not reflect shipping costs. Prices in this study are as follows: flat plate ($2.00 each), preassembled groove plate ($15.00 each), 7018 electrode ($3.09 per pound).

Real-World Cost Implications

When factoring in the costs for the material, the total dollar value of the flat plate used in the VRI group was $420; the flat plate used by the TT group was $576. Similarly, the total dollar value for the VRI groove plate was $750 while the groove plate cost for the TT group was $945. The total dollar value for the amount of electrode used was again less for the VRI group. The electrode dollar value for the VRI group was $343.61, compared to the TT group value of $579.71. When all materials usage is considered, the total materials training cost for the VRI group was $1513.61, compared to $2100.71 for the TT group. This equates to a per-student cost of $137.6 for participants in the VRI group and a per-student cost of $190.97 for participants in the TT group.

Virtual-World Cost Savings

The equivalent virtual cost represents the hypothetical materials cost that would be generated if the virtual machine actually charged for plates and electrodes. The equivalent virtual cost for the flat plate would have been $680. The equivalent virtual cost for the groove plate would have been $1710. The equivalent virtual cost for the 7018 electrodes would have been $290.46. The total equivalent virtual cost savings, when all factors are considered, equate to $2,680.46. That is a per-student savings of $243.68.

Discussion

The study described in this paper aimed to determine the effect of modern VR training technology in the domain of welding. The overall effectiveness of VR integrated training was examined in terms of training potential, team learning, material demand, and cost. These issues will be discussed by addressing the hypotheses of this paper.

The authors' first hypothesis was that VR integrated training would result in superior training outcomes when compared to traditional methods. In all cases, participants in the VRI group had a greater percent transfer and a far superior TER than participants in the TT group. The VRI group was not only able to surpass the TT group in terms of absolute effectiveness, but they were able to do so with a significantly shorter amount of training time.

This finding strongly supports the use of VR integrated training at the 50% level, and supports the first hypothesis.

The second hypothesis stated that the use of the VR system would lead to increased levels of team interaction and learning. The results from the team interaction and learning analysis showed that for the continuous-improvement-seeking dimension there was no significant difference between the two groups. This indicates that there was no difference in participants' desire to perform well and to learn from their experience between the VRI and TT groups. However, the VRI group did have significantly higher values for the dialog and open communication as well as the collaborative learning dimensions. These results confirm this second hypothesis. Moreover, these results indicate participants in the VRI group were much more willing to communicate and lean from their cohorts. The VR machine provided a conduit by which participants not only were more likely to communicate, but were more likely to value the communication and use it to improve their skills. Team learning was a positive factor in the superior training outcomes associated with VR integrated training.

The third hypothesis was that the weld training conducted with VR integrated technology would be significantly less expensive than training conducted using traditional means. The results of cost analysis clearly confirm this hypothesis. For each type of consumable used in this investigation, the total cost of the material was less for the VRI group compared to the TT group. The VR machine allowed students to practice welds without the need to invest time in setup and material-gathering procedures. As such, the students in the VR group had the opportunity to utilize more plates. If the virtual machine had charged for the consumables, the VRI would have cost twice as much, this despite costing markedly less in terms of the real cost of the physical goods. Further, the ability (afforded by the virtual training system) to abandon a poor weld and start over without the consequence of wasted materials could have been greatly beneficial to the welding students. For example, it was often observed that when students in the VRI group were told (by the partner relaying the machine's score) they had a bad root pass, they would often start over with a new plate. From the students' perspective there was no need to worry about wasting steel or losing the time involved in assembly and re-tacking.

Conversely, students in the TT group were less likely to be aware they had a bad root pass, and even when aware they would retain the plate to avoid setup and wasted plate/money. The increased number of practice welds created by students in the VRI group was a likely contributor to their superior percent transfer and TER. The VR system also allowed the participants to focus on the areas of a weld they needed to practice the most. For example, if they needed to practice the root pass, they could start over on a new piece every single time. This activity could not be feasibly replicated using traditional means of training.

Analysis of the VR system's impact on the human operators indicate that there were at least three major attributes that contribute to the success of the VR weld trainer. The first being the fully immersive environments that allow for the manipulation of physical weld tools. This allows the user to develop sensory motor memories that were appropriate for use in real-world welding situations. Second was the use of feed-forward visual overlays and postweld feedback in the VR system that allowed users to improve specific aspects of their welds during training. This level of oversight and guidance is simply not possible during normal weld training due to environmental factors and time constraints. The third and final attribute was the increased volume of practice weld achievable in the VR environment. By eliminating material transfer and setup times, participants in the VRI group were able to gain more practical experience by spending more time in the commission of a weld than their real-world counterparts. Hence, a successful VR solution should incorporate these key characteristics.

The authors' future work will include a 100% VR weld school. The experiment will be conducted in a similar fashion to the current study, with the exception being that the CWI will only oversee testing as opposed to conducting instructional operations. This study will aid in further understanding of the effectiveness of VR for weld training.

Conclusions

The results of this study clearly show the direct benefits of using virtual reality integrated training in the domain of welding. The students in the VRI group demonstrated vastly superior training outcomes when compared to their traditionally trained (TT) counterparts. Following are two factors that are associated with this outcome: 1) the significantly higher levels of team learning and interaction between VRI students, and 2) the significantly greater amount of welds performed by VRI students in the VR environment. In addition to fostering greater learning success, the use of VR integrated training greatly reduces training-associated costs.

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