Augmenting Welding Training: An XR Platform to Foster Muscle Memory and Mindfulness for Skills Development

Tate Johnson
tatej@alumni.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Ann Li
annli@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Andrew Knowles
aknowles@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Zhenfang Chen
zhenfanc@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Semina Yi
seminay@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Yumeng Zhuang
yumengzh@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Dina EL-Zanfaly
delzanfa@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Daragh Byrne
daraghb@andrew.cmu.edu
Carnegie Mellon University
Pittsburgh, USA

Figure 1: Integrated XR welding helmet and torch system.

ABSTRACT

Metal welding is a craft manufacturing skill that can be unusually difficult to externalize and represent to novices. Building competency requires an apprentice to iteratively practice embodied skills and sensitize themselves to a sensorially complex practice. To explore these challenges, we identified opportunities for mixed reality and meditation processes to augment welding training and practice. Our demo showcases an extended reality (XR) welding helmet and torch that enhances the embodied learning of welding. We do this in two key ways: biometric sensing that enhances mindfulness and stress management in sensorially challenging environments, and combined motion-sensing and visual XR feedback that helps improve proprioceptive and embodied learning.

ISS Companion '23, November 05–08, 2023, Pittsburgh, PA, USA

ACM ISBN 979-8-4007-0425-3/23/11.
https://doi.org/10.1145/3626485.3626544

CCS CONCEPTS

• **Human-centered computing** → *User interface toolkits*; User interface programming; **Mixed / augmented reality**;

KEYWORDS

Augmented Reality, 3D Interaction, Prototyping, Craft, Toolkits, Embodied Interaction, Ubiquitous Computing, Smart Objects and Environments

ACM Reference Format:
Tate Johnson, Ann Li, Andrew Knowles, Zhenfang Chen, Semina Yi, Yumeng Zhuang, Dina EL-Zanfaly, and Daragh Byrne. 2023. Augmenting Welding Training: An XR Platform to Foster Muscle Memory and Mindfulness for Skills Development. In *Companion Proceedings of the Conference on Interactive Surfaces and Spaces (ISS Companion ’23), November 05–08, 2023, Pittsburgh, PA, USA*. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3626485.3626544

1 INTRODUCTION

Many industries rely on skilled welders to produce the products we use daily. Attracting and retaining novice welders within training opportunities has, however, become increasingly challenging. The American Welding Society predicts a deficit of 375,000 welders in the United States by 2024 [11]. The shortage of welding operators can be attributed to two main factors: negative perceptions surrounding the profession and the challenge of replacing retirees with younger generations [11]. This suggests a need for increased creativity in training young welders. Training welders requires developing complex embodied knowledge across hand-eye coordination, movement, proprioception, and sound. This embodied knowledge is acquired through in-situ apprenticeship and hands-on interactions with tools and materials [4]. These attributes can be complex to understand and hard to replicate in training scenarios. As such, systems are needed that can support the development of this embodied knowledge in a more experientially efficient and rich way than by simply ‘welding more’. Prior research and commercial products have explored XR (extended reality) and VR (virtual reality) in possible welding augmentation [12, 18–21], but these systems are generally designed for classrooms or settings without active welding.

Our demonstration responds to this need by creating a functional XR- and ML-enabled welding system that supports augmented welding training. The primary contribution of this work is the system and approach of augmenting embodied understanding — eye-hand coordination, active listening, and mindfulness — to help novice learners manage and navigate a challenging craft practice. A secondary contribution is the development of open-source software for the Quest platform that makes our interactive design available to other researchers as a resource to examine XR-driven craft augmentation.

2 RELATED WORK

Mixed reality systems have enabled research on immersive experiences in education, embodiment, handcraft, and welding. Prior work explores the approaches of these experiences in entertainment and education [10], as well as guidelines on the relationship between the virtual world and physical embodiment [2, 7, 9]. There have been some approaches leveraging XR simulations to accelerate crafts training [3] and to enable students to enter the workforce more rapidly [5]. For MIG welding, previous research has created AR, VR, and specialized peripherals for welding simulators that allow users to experience an immersive environment for setting up, executing, and validating welding processes [12, 18, 19, 21]. Publicly available products such as the Miller AugmentedArc system, Lincoln Electric VRTEX 360, Soldamatic, and guideWELD® VR welding simulator help beginners develop muscle memory in a safe and effective manner, but use costly and abstracted systems. Muscle memory and the performance of skilled activities can be greatly enhanced by mindfulness routines. For example, existing research found that mindful breath patterns can improve academic performance [6], change emotional state [15], and improve performance when operating vehicles [1, 13, 14]. Projects have also leveraged technology to create systems that support the awareness of breathing [16] and further explore enhancing mindfulness design through breathing in a mixed reality environment [17]. To our knowledge, no work to date has investigated computer-supported mindfulness in welding activities.

3 EXPERIENCE OVERVIEW

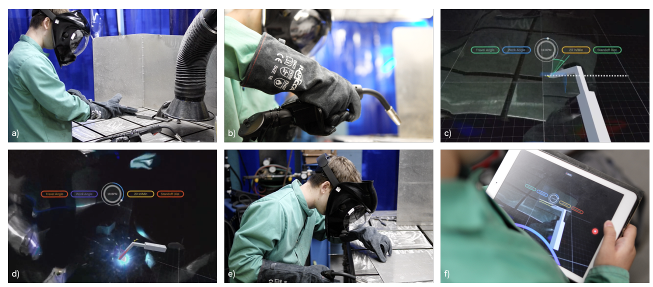

Figure 2: User experience of using XR Welding

Although our system is designed and primarily intended for in-situ (live welding) use (see Figure 2), it can also be used to practice welding through augmented reality when not in-situ. In this case, the XR welding helmet and gun will simulate the experience of the welding arc by adding sounds and animations (e.g. welding sparks.) This enables participants to practice welding and experience the real-time meditation and embodied XR feedback of our system when not engaged in active welding tasks.

Our experience begins with participants getting accustomed to the augmented helmet and gun devices. They also participate in the guided breathing meditation exercise to improve their focus before welding (Figure 2.a). Next, to calibrate the XR representation of the weld to a real work surface, the start and endpoints of the weld line can be set by the user (Figure 2.b). As the participant begins to ’weld’, the system provides real-time visual feedback on the different speeds, angles, and variances from ideal welding behaviors (Figure 2.c). If an actual arc is present, the pass-through display automatically dims to maintain the graphical user feedback throughout the weld (Figure 2.d). After a weld (virtual or real) is finished, the participant can review their weld line performance in 3D space, reflecting on their performance and variance (Figure 2.e).

Finally, an ’instructor’ or demonstration onlooker can see the real-time point-of-view experience of the welding participant, as well as review the experience asynchronously with the other participant (Figure 2.f).

4 TECHNICAL APPROACH

4.1 XR Visual Feedback

We created a series of visual feedback mechanisms for the XR headset display. We used two separate XR indicators for work and the weld gun travel angle in order to make slight changes and adjustments visible (see Figure 3). The indicators, along with status icons presented near the top of the viewport, allow users to see feedback without taking focus away from an active weld. The status icons, by contrast, can give a much clearer overview of performance for instructors or users viewing live playback, particularly when focusing on the tip of the welding gun is not as important.

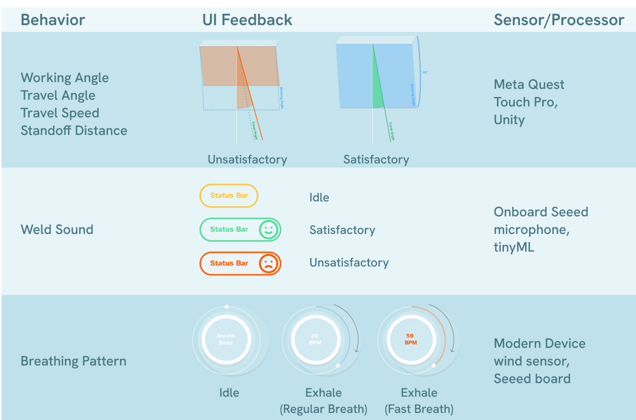

Figure 3: Visual XR UI

4.2 Device Design

To provide support for and to evaluate these experiences, we created a functional device system that integrates sound and breath sensing with a Meta Quest Pro headset and a standard MIG welding helmet and gun. We interfaced the Seeed ESP32S3 board with a Unity program running the XR display, using the Quest Pro’s USB-C port and the Serial Port Utility Pro plugin [1]. A 3D-printed enclosure interfaces a Quest Touch Pro controller with a welding stick, aligning the independent systems together as well as protecting the controller from weld spatter and heat. Using the existing buttons on the Touch Pro controllers allows users to control different settings such as POV recordings, spatial calibration, and navigating the Quest UI.

4.3 Pre-welding Meditation

Novices to welding can be overwhelmed and stressed by the overpowering sensory cues, such as sparks, heat, and scents. While there has been research into helping welders become accustomed to a sensorially demanding task through XR simulation, this work has been limited to welding practice in non-in-situ environments and to building a learner’s exposure to the sonic and visual experience of welding [8]. While at our partner welding site, the Industrial Arts Workshop, we observed that when learners engage in breathing exercises and meditation it can help induce relaxation, foster a sense of focus on the task and materials, and build proprioceptive awareness. As such, we saw an opportunity to explore how such mindfulness practices can be scaffolded and augmented with technology-mediated support.

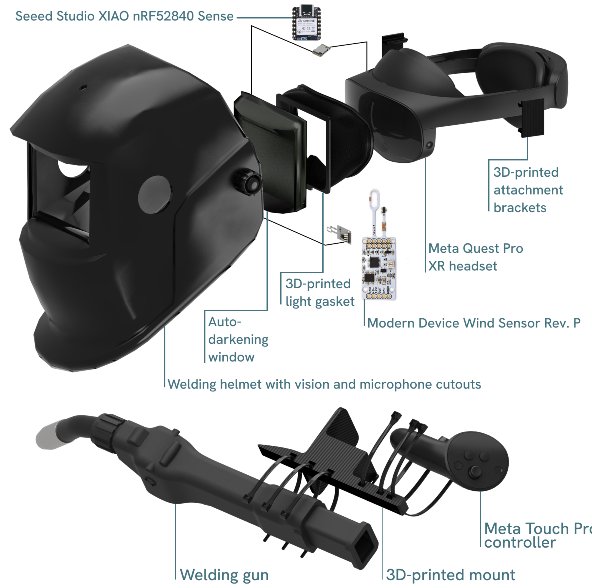

Figure 4: Device assemblies

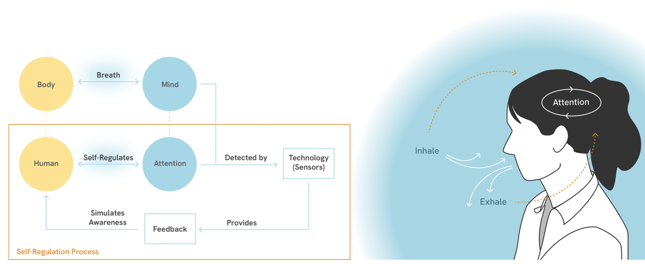

Figure 5: Meditation and attention

We leverage the welders’ breath as an input for our AR system (see Figure 5). We use an off-the-shelf anemometer to track breathing. As an indicator of stress and well-being during welding tasks, we gather real-time data on the user’s breathing rates through this sensor and present the readings within the XR UI (see Figure 3.) When the platform is initialized, each trainee is encouraged to engage in breathing exercises before the welding session. This action also serves to calibrate the sensor to the individual. We expect that such interactive strategies will help learners practice

[1] https://assetstore.unity.com/packages/tools/utilities/serial-port-utility-pro-125863

and adopt mindfulness techniques that will ultimately benefit task performance and eye-hand coordination.

5 CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

We demonstrate a multimodal XR system for training of the welding process. Our system explores the incorporation of mindfulness and multisensory awareness into skill building through breath meditation, as well as improving the embodied skill-based practice of welding by leveraging augmented reality. The system used in our demo consists of two main components: an augmented welding torch for hand-tracking and a welding helmet with an integrated XR headset and a breath sensor. The system provides real-time visual feedback on welding torch movements and enables the learner to practice mindfulness with breathing exercises to improve focus and craft-building. There are some limitations to our approach. In-helmet XR further restricts the already limited field of view within the protective helmet by adding a significant amount of visual interface elements. Additionally, ergonomics remain a challenge. The headset is heavy for prolonged use and the visual pass-through of the XR can offer less than optimal quality for some welding tasks. Future work will explore ways to improve the ergonomics of our XR setup, refine the implementation of breath monitoring and feedback, and examine the potential haptic feedback to reduce the need for on-screen displays. In addition, we plan to assess how our XR training affects welding skill acquisition for novices.

ACKNOWLEDGMENTS

We would like to thank Tim Kaulen, staff, and students at our partner organization, the Industrial Arts Workshop, for their time and expertise. This work was funded by the Manufacturing Futures Institute at Carnegie Mellon University.

REFERENCES

[1] Stephanie Balters, Matthew L. Mauriello, So Yeon Park, James A. Landay, and Pablo E. Paredes. 2020. Calm Commute: Guided Slow Breathing for Daily Stress Management in Drivers. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 1 (March 2020), 1–19. https://doi.org/10.1145/3380998

[2] Selena Chan, Lee Bagalow, and Chris Lovegrove. 2019. Supporting the learning of the sociomaterial: novices' perspectives on virtual reality welding simulators. In *Contemporary Apprenticeship Reforms and Reconfigurations*. 63–66. https://books.google.com/books?hl=en&lr=&id=1tmRDwAAQBAJ&oi=fnd&pg=PA63&dq=embodied+learning+welding&ots=QEiVrL62j3&sig=lUNC9sfY8FNi1MVwwcgaXZOW6LE#v=onepage&q=embodied%20learning%20welding&f=falsein

[3] Atsushi Hiyama, Hiroyuki Onimaru, Mariko Miyashita, Eikan Ebuchi, Masazumi Seki, and Michitaka Hirose. 2013. Augmented Reality System for Measuring and Learning Tacit Artisan Skills. In *Human Interface and the Management of Information. Information and Interaction for Health, Safety, Mobility and Complex Environments*, Sakae Yamamoto (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 85–91.

[4] Tim Ingold. 2021. *The Perception of the Environment: Essays on Livelihood, Dwelling and Skill* (1 ed.). Routledge, London. https://doi.org/10.4324/9781003196662

[5] Ananya Ipsita, Levi Erickson, Yangzi Dong, Joey Huang, Alexa K Bushinski, Sraven Saradhi, Ana M Villanueva, Kylie A Peppler, Thomas S Redick, and Karthik Ramani. 2022. Towards Modeling of Virtual Reality Welding Simulators to Promote Accessible and Scalable Training. In *CHI Conference on Human Factors in Computing Systems*. ACM, New Orleans LA USA, 1–21. https://doi.org/10.1145/3491102.3517696

[6] Kiat Hui Khng. 2017. A better state-of-mind: deep breathing reduces state anxiety and enhances test performance through regulating test cognitions in children. *Cognition and Emotion* 31, 7 (Oct. 2017), 1502–1510. https://doi.org/10.1080/02699931.2016.1233095

[7] Konstantina Kilteni, Raphaela Groten, and Mel Slater. 2012. The Sense of Embodiment in Virtual Reality. *Presence: Teleoperators and Virtual Environments* 21, 4 (Nov. 2012), 373–387. https://doi.org/10.1162/PRES_a_00124

[8] Olena O. Lavrentieva, Ihor O. Arkhypov, Olexander I. Kuchma, and Aleksandr D. Uchitel. 2020. *Use of simulators together with virtual and augmented reality in the system of welders' vocational training: past, present, and future.* Technical Report. https://doi.org/10.31812/123456789/3748

[9] Jo Mackiewicz. 2022. *Welding Technical Communication: Teaching and Learning Embodied Knowledge.*

[10] Sheila L. Macrine and Jennifer M.B. Fugate. 2020. Embodied Cognition. In *Oxford Research Encyclopedia of Education*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190264093.013.885

[11] Kierstin Nash. 2023. Robotic Welder Combats Labor Shortage to Boost American Businesses. https://www.thomasnet.com/insights/robotic-welder-combats-labor-shortage-to-boost-american-businesses/ Publication Title: Thomas Insights.

[12] Maria Lucia L.R. Okimoto, Paulo César Okimoto, and Carlos Eduardo Goldbach. 2015. User Experience in Augmented Reality Applied to the Welding Education. *Procedia Manufacturing* 3 (2015), 6223–6227. https://doi.org/10.1016/j.promfg.2015.07.739

[13] Pablo E. Paredes, Stephanie Balters, Kyle Qian, Elizabeth L. Murnane, Francisco Ordóñez, Wendy Ju, and James A. Landay. 2018. Driving with the Fishes: Towards Calming and Mindful Virtual Reality Experiences for the Car. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 4 (Dec. 2018), 1–21. https://doi.org/10.1145/3287062

[14] Pablo E. Paredes, Yijun Zhou, Nur Al-Huda Hamdan, Stephanie Balters, Elizabeth Murnane, Wendy Ju, and James A. Landay. 2018. Just Breathe: In-Car Interventions for Guided Slow Breathing. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 1 (March 2018), 1–23. https://doi.org/10.1145/3191760

[15] Pierre Philippot, Gaëtane Chapelle, and Sylvie Blairy. 2002. Respiratory feedback in the generation of emotion. *Cognition & Emotion* 16, 5 (Aug. 2002), 605–627. https://doi.org/10.1080/02699930143000392

[16] Mirjana Prpa, Ekaterina R. Stepanova, Thecla Schiphorst, Bernhard E. Riecke, and Philippe Pasquier. 2020. Inhaling and Exhaling: How Technologies Can Perceptually Extend our Breath Awareness. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–15. https://doi.org/10.1145/3313831.3376183

[17] Mirjana Prpa, Kıvanç Tatar, Jules Françoise, Bernhard Riecke, Thecla Schiphorst, and Philippe Pasquier. 2018. Attending to Breath: Exploring How the Cues in a Virtual Environment Guide the Attention to Breath and Shape the Quality of Experience to Support Mindfulness. In *Proceedings of the 2018 Designing Interactive Systems Conference*. ACM, Hong Kong China, 71–84. https://doi.org/10.1145/3196709.3196765

[18] Richard T. Stone, Elease J. McLaurin, Peihan Zhong, and Kristopher P. Watts. 2013. Full Virtual Reality vs. Integrated Virtual Reality Training in Welding. *Welding Journal* 92 (2013). https://api.semanticscholar.org/CorpusID:55015136

[19] Yizhong Wang, Yonghua Chen, Zhongliang Nan, and Yong Hu. 2006. Study on Welder Training by Means of Haptic Guidance and Virtual Reality for Arc Welding. In *2006 IEEE International Conference on Robotics and Biomimetics*. IEEE, Kunming, China, 954–958. https://doi.org/10.1109/ROBIO.2006.340349

[20] Steven A. White, Mores Prachyabrued, Terrence L. Chambers, Christoph W. Borst, and Dirk Reiners. 2011. Low-cost simulated MIG welding for advancement in technical training. *Virtual Reality* 15, 1 (March 2011), 69–81. https://doi.org/10.1007/s10055-010-0162-x

[21] Ungyeon Yang, Gun A. Lee, Yongwan Kim, Dongsik Jo, Jinsung Choi, and Ki-Hong Kim. 2010. Virtual Reality Based Welding Training Simulator with 3D Multimodal Interaction. In *2010 International Conference on Cyberworlds*. IEEE, Singapore, Singapore, 150–154. https://doi.org/10.1109/CW.2010.68

Received 2023-08-15; accepted 2023-09-15