Institution: Oxford Brookes University		
Unit of Assessment: 11, Computer Science and Informatics		
Title of case study: Setting the New Standard for Human Performance Improvement using Augmented Reality		
Period when the underpinning research was undertaken: 2016–2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr Fridolin Wild	Senior Research Fellow	[text removed for publication]
Period when the claimed impact occurred: 2016–2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research by Oxford Brookes' Performance Augmentation Lab (PAL) led to the creation of an international standard by the world's most prestigious professional body in engineering, the Institute of Electrical and Electronics Engineers (IEEE). This standard defines how industry across the globe should design and develop products that use virtual and augmented reality technology to train and up-skill workers. The research undertaken by Dr Fridolin Wild at PAL resulted in novel augmented reality and wearable technology to up-skill workers in industry and service related sectors. Through the development of Virtual Reality (VR), Augmented Reality (AR) and Wearable Technology (WT) an innovative system has been developed that enables training software to be produced at low cost and at scale. This allows effective training – enabling new skills, knowledge, and abilities, addressing skills gaps and reducing costs for employers.

2. Underpinning research

Human Performance Augmentation refers to the process of equipping users with wearable and pervasive computing technology that allows them to apply abstract knowledge into practical application (e.g. training in high-risk situations) and, ultimately, act at a level of mastery otherwise not achievable **[3.1]**.

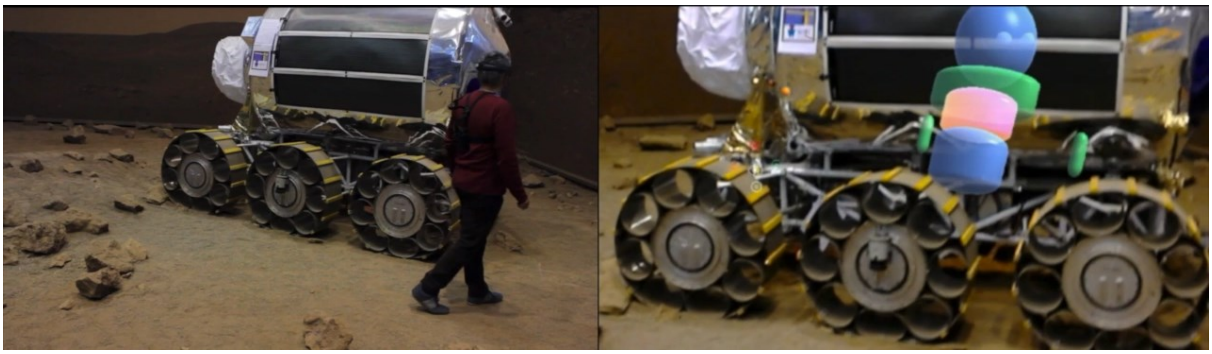
The Performance Augmentation Lab at Oxford Brookes University created a ground-breaking, in situ, authoring system that helps overcome the content production barrier for 3D augmented reality training content. We created a novel software development framework for experience capture and sharing **[3.2]**. Expert users wear the glasses and the e-textile to move freely around in their workplace without motion sickness effects **[3.3]**, to record a sequence of guiding steps, using so-called 'task stations' (points of interest in the environment) to anchor multimodal content they select or produce. The content can be stored to the cloud and used in disparate locations, such as in space. Under different conditions, the software adapts to the local work environment automatically, before a trainee can replay the guidance sequence that directs the task **[3.4]**.

Our research, developed across four major grants, provides a new approach. Building on earlier work (EUR8,300,000 H2020-funded TELLME project, 2012–2015), Wild coordinated, as scientific director, the EUR2,753,000 H2020 funded WEKIT project (2015–2019), which advanced from a proof of concept for Augmented Reality specification (Technology Readiness Level 3), to an industrial strength platform (TRL 7) that supports the wearer of AR devices. The project validated the developed methodology and technology in three pilot test-beds in aviation,

space engineering, and medicine, where the application is especially relevant **[3.2]**.

The EUR7,741,697 H2020 funded TCBL project (2015–2019), running in parallel, complemented this with further technology development and test cases in the textile and clothing industry. Within the EUR4,000,000 H2020 funded ARETE project (2019–2022) we enhanced the technology into a more collaborative, cross-device/cross-platform by adding an AR abstraction layer over the vendor-specific AR toolkits, complementing it with groupware technology to allow for the orchestration of classroom-sized audiences, which has not previously been achieved.

A key invention in this context, for experience capture, includes the 'ghost track' recording and replay, which uses simplified motion sensing with sensor fusion from e-textile integrated sensors and smart glasses for recording. This allows us to calculate and deliver a 3D holographic character presence in replay, re-enacting expert movement in the real environment while replaying a think-aloud audio protocol, with the expert now absent. This is illustrated in the figure below.



Example of the AR Ghost Track on Mars Surface Simulator capturing (left) the instructor workflow and (right) AR view of the trainee with ghost instructor visible **[3.3, 3.5]**

Our research on Performance Augmentation is world leading. Fridolin Wild was appointed the chair of the IEEE standard development. This is an extension of the specification for Augmented Reality Learning Experience Models (ARLEM, IEEE standard association working group p1589, **[3.6]**. The representation standard provides a conceptual model guiding implementation by software manufacturers, while establishing interoperability for an open market of Augmented Reality learning content. Further, we have devised architectural blue prints, frameworks, and extracted design patterns for Performance Augmentation as exemplified by the software developed:

S1. WEKIT.one: Application for capturing and re-enacting experience (closed source)
S2. DAIMON: Holographic AI with speech recognition, synthesis, and dialogue interaction, https://github.com/Yu713/daimon
S3. UNBODY: mixed reality arts installation, probing the boundary between identity and consciousness in an extended reality. Shortlisted for the Auggie Awards 2020, nominated for Ars Electronica and the Starts Innovation Prize: https://github.com/fwild/PoetryEscapeRoom
S4. HOLOCARE: live sized, interactive holographic characters for digital healthcare, https://github.com/fwild/holocare

3. References to the research

[3.1] Buchem I, Klamma R, Wild F (2019) Introduction to Wearable Enhanced Learning (WELL): Trends, Opportunities, and Challenges, In: Buchem, Wild, Klamma (Eds.): *Perspectives on Wearable Enhanced Learning (WELL): Current Trends, Research, and Practice*, Springer ISBN: 978 3319643014

[3.2] Sharma P, Klemke R, Wild F (2019) Experience Capturing with Wearable Technology in the WEKIT project, In: Buchem, Wild, Klamma (Eds.), *Perspectives on Wearable Enhanced*

Learning (WELL): Current Trends, Research, and Practice, Springer ISBN: 978 3319643014

[3.3] Vovk A, Wild F, Guest W, Kuula T (2018) Simulator Sickness in Augmented Reality Training Using the Microsoft HoloLens, In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1-9. DOI: 10.1145/3173574.3173783

[3.4] Guest W, Wild F, Vovk A, Lefrere P, Klemke R, Fominykh M, Kuula, T (2018) A Technology Acceptance Model for Augmented Reality and Wearable Technologies, In: *Journal of Universal Computer Science* 24 (2), 192-219. DOI: 10.3217/jucs-024020192

[3.5] Ravagnolo L, Helin K, Musso I, Sapone R, Vizzi C Wild F Vovk A, Limbu B, Ransley M, Smith C, Rasool J, (2019) Enhancing Crew Training for Exploration Missions: the WEKIT experience, In: *International Astronautical Congress*, October 20-25, 2019, Washington DC, US

[3.6] Alarcon R, Wild F, Perey C, Marin Genesca M, Gavalda Martinez J, Ruiz Marti JX, Simon Olmos MJ, Dubert D (2020) Augmented Reality for the enhancement of space product assurance and safety, In: *Acta Astronautica* 168, 191-199. DOI: 10.1016/j.actaastro.2019.10.020

4. Details of the impact

Impact on Multipliers: software vendors, public sector, other leaders in the field

The IEEE is the key professional body for engineering, computing and technology around the world, with over 419,000 members in 160 countries. In January 2020, the Standards Board of the IEEE Standard Association (which contains representatives of leading technological nations, international standards institutes and accreditation bodies of all major nations), approved P1589/Draft3, an Augmented Reality Learning Experience Model.

This P1589 standard **[5.1]** is currently the only standard for delivery of interactive AR content across the key standardisation bodies, IEEE, MPEG, ISO, ETSI, CEN/CENELEC. The IEEE subcommittee was chaired by Fridolin Wild and the framework is based on his work. It enables vendors and other stakeholders (such as in public procurement) to quickly adopt an approved conceptual model and component architecture for AR training, and provide AR content at scale. This lowers entry barriers to authoring of learning and training experiences, and facilitates the creation of online repositories and market places. It allows manufacturers and developers to ensure that the product meets the required criteria for valid and effective use for the wearer and the task designer.

Within the European Space Agency, a shared vision ("New Space", "Space 4.0") and according digital agenda is gradually emerging. Performance Augmentation technologies have an important role in this, for example in product assurance and safety, in astronaut training and autonomous support. An empirical study, conducted by Wild's team among personnel from ESA, other space agencies and industry (in total 56 organisations) was carried out to develop the technology roadmap for AR in space product assurance and safety. It showed most appreciation for the deployment of performance augmentation technologies for the use cases of operator training and process management, quality inspection and testing, non-conformance documentation, configuration management, and linking in of remote experts **[3.6]**. The studies conducted **[S1, 3.6]** provide strong evidence that operator training and process management can be supported successfully with AR. The ESA expert workshop held by Wild's team on AR/VR for European space programme rated standardisation (with 64%) as the most important area for ESA to invest into in order to leverage the use of AR/VR in space missions **[5.7]**.

Impact on Industry: creating real products

The research outputs are deployed in the aviation, textiles, space, medical and healthcare sectors, and the creative industries. Several companies are building economic success from technologies enabled by the research conducted: for example, ALTEC S.p.a. (Aerospace Logistics Technology Engineering Company), EBIT, PaceLab, WordsWorthLearning, Microsoft

and WEKIT ECS **[5.3, 5.6]**.

ALTEC continues to exploit the WEKIT applications, to augment the training process for astronauts and to support future space exploration, including on Mars. ALTEC Space have proposed to the major space agencies further testing with crew members and scientists in so-called 'analogue' environments like Pangaea or Concordia **[5.5]**.

The WEKIT software provided the foundation for the MobiPV procedure viewer and the MobiPV4Hololens app of the European Space Agency (developed by VTT, based on existing code).

Through its IT company EBIT, Esaote offers healthcare IT systems for workflow management of radiology and cardiology diagnostic processes. EBIT says about the WEKIT software solution: "AR authoring and training has other advantages: it takes less time than conventional training; could be easily repeated; provides more detailed information in complex cases; and may provide real time comparison results without the presence of the expert" **[5.5]**. Both EBIT and Esaote are proceeding to experiment further with the devices to support equipment and software for augmenting physicians' diagnostic procedures with AR **[5.4]**.

A Milan-based, 600 employee company (with subsidiaries in Italy, Germany, UK, France, Switzerland, USA), TXT has developed the Pacelab WEAVR system, which is now one of the major products in aerospace, used for on-the-job training of pilots, cabin crew, maintenance technicians, and field technicians (with additional applications in marketing) (https://www.txtgroup.com/markets/solutions/pacelab-weavr/). It encompasses virtual training (https://www.txtgroup.com/markets/solutions/virtual-training/) and operation support use cases (https://www.txtgroup.com/markets/solutions/armr-field-support/). TXT created a start-up to experiment on AR for new markets outside of aerospace (https://sense-immaterialreality.com/). **[5.2]** The experience with our EC funded projects and the IEEE standard in development was one of the key stepping-stones for that.

A spin out company is linking research with industry (WEKIT ECS Ltd). WEKIT ECS has developed an AR training system implementing the standard.

Impact on People and Economic Benefits

WEKIT has shown the benefits of using experience captured through automated extraction from users' real-world demonstration and live guidance solution. The impact assessment from the evaluations across the user validated projects found **[5.4, 5.5]**, that:

- Live guidance enables upskilling on the job: We were able to show that the autonomous AR and wearable technology performance augmentation solution performs equally as well as traditional training methods. **[5.4, 5.5]**
- The research outputs help to drastically reduce training time (for Mars the predicted amount of training needed rises to 6 years for a 2-3 year mission, which is no longer feasible). Furthermore, it provides autonomy where other support is not available (e.g. in deep space missions, where communication with ground control takes 8-24 min depending on distance from Earth to Mars) **[3.4]**.
- Experts and trainees assess a high level of acceptance, with a positive attitude towards the technology, a high level of hedonic motivation to use, and low effort expectancy when working with the technology. The system is considered stimulating, and easy to use. **[3.5]**

WEKIT ECS is a company of 15, currently engaging in valuation and approaching investors. The training methodology and systems of the WEKIT project can reduce costs by up to 85%, serving a market of 1,500,000 companies in the EU who paying for training, spending EUR13,800,000 in total every hour **[5.7]**. Supported by the IEEE standard, WEKIT ECS is in an excellent position to ensure growth and wider impact, leading future developments in AR and VR.

5. Sources to corroborate the impact

[5.1] IEEE P1589-2020: Standard for Augmented Reality Learning Experience Model, https://standards.ieee.org/standard/1589-2020.html. Fridolin Wild is the appointed chair of the standards working group, assisted by co-chair Christine Perey (Perey Research and Consulting, Switzerland) and Brandt Dargue (Boeing, USA).

[5.2] Letter from Mixed Reality and Digital Innovation Manager, TXT: Confirms how PAL's research contributes to the new flagship product Pacelab WEAVR.

[5.3] Letter from Microsoft Product Director for Mixed Reality, UK: Confirms the impact of PAL's work on Microsoft's market development, specifically highlighting PAL's role in supporting the industry in adoption, and training new software developers.

[5.4] WEKIT Deliverable D6.11: Evaluation and impact assessment of the WEKIT project results in healthcare. Contains peer reviewed scientific experiments conducted in collaboration with experts dedicated to the use of the platform in the field of healthcare training (EBIT/Esaote).

[5.5] WEKIT Deliverable D6.12: Evaluation and impact assessment of the WEKIT project results in space. Contains peer reviewed scientific experiments conducted in collaboration with ALTEC and Thales Alenia Space.

[5.6] Letter from WordsWorthLearning: States the importance of the IEEE standard for their literacy development app, helping students overcome dyslexia

[5.7] ESA expert workshop on AR/VR for European Space Programmes: Rates standardisation as the most important area for ESA to invest into in order to leverage the use of AR/VR in space missions

[5.8] UNBODY listed as one of five finalists for the category 'Best Art or Film' at the Augmented World Expo (AWE) 2020 Auggie awards in Santa Clara, US: https://www.awexr.com/blog/269-finalists-announced-for-the-11th-annual-auggie-awa