

Development of a Mixed Reality Game for Simulation Based Education

Sam Harper, Aparajithan Sivanathan, Theodore Lim, Scott McGibbon, James Ritchie
Heriot-Watt University, Edinburgh, UK

sh324@hw.ac.uk

A.Sivanathan@hw.ac.uk

T.Lim@hw.ac.uk

sm604@hw.ac.uk

J.Ritchie@hw.ac.uk

Abstract: Mixed reality allows for new ways for learners to enrich their learning experience. By enabling the use of 3D virtual content in a tangible space, it offers a more immersive digital learning environment than traditional on-screen methods. This paper reports on the use of the Mixed Reality (MR) Microsoft HoloLens to create a mixed reality Vocational Educational Training (VET) serious game.

The main challenges of this investigation are the use of tangible objects as an interface to a virtual learning environment, which is achieved through low-latency, real-time tracking, allowing for believable interaction with virtual content. This is examined through the creation of a stone cutting application incorporating the use of a 9' angle grinder for training college-level stonemasons, whereby the learner attempts to cut a cheek into a virtual stone block using a real grinder. Cyber-physical systems (CPS) are utilised to realise this as part of the digital pedagogy. Currently, the vocational training is constrained by organisational health and safety regulations which do not allow students to use power tools such as an angle grinder within the college. By using a virtual stone block, a 'real' physical grinder as a tangible interface can be used without the associated safety risks.

The application has been co-designed and developed in association with several further education (FE) colleges in Scotland and has received appraisals from teachers and learners. On-site demonstrations have been carried out, with the mixed reality operation alongside a PC-based, mouse-operated application. Early feedback has suggested that as a method for technical and vocational training (TVET), it is a system that FE colleges would consider as an innovative Technology-enhanced Learning and Teaching (TELT) and be susceptible to its future use both within a classroom and workshop environment. This work builds upon research carried out for the BEACONING program, part of the Horizon 2020 framework.

Keywords: Mixed Reality, HoloLens, Cyber-physical system, VET, Simulation based education, Serious Games

1. Introduction

One of the most important aspects of any digital learning environment is the emulation of real-world settings. The MR VET application was developed based on a computer-based training game developed by Imaginary for the BEACONING program. The desktop application uses a mouse-based interface to carry out all the steps of a grinding procedure as a training tool to assist with learning the methodology required for stonemasonry. However, without a tangible link to the real world, the pedagogical aspects of this application may be somewhat limited, as the actual use of an angle grinder is impossible to simulate with a mouse interface. The MR application has been designed to reflect this need for more practical training.

1.1 The use of MR in pedagogy

Technology-enhanced Learning and Teaching (TELT) in the field of pedagogy, centres around technology which can be used to assist learning in ways traditional pen-and-paper methods cannot. Currently, in the field of construction technical and vocational training (TVET), particularly for the training field of stonemasonry, students are unable to use "live" working angle grinders in their current learning environment, typically within a workshop area, on real stone due to the associated health and safety risks. Yet, the use of an angle grinder is a vital component in the day-to-day work of a modern stonemason, hence the lack of effective prior angle grinder experience for trainee stonemasons affects not only the operatives ability to safely and appropriately use such a power tool through their learning cycle. It also affects the future employment prospects, for newly qualified operatives, given employers require the workforce to be work-ready and are reluctant to employ an

operative who does not have the required experience and knowledge. Using MR, it can be possible to provide a realistic training environment without the associated health risks, ensuring the student is equipped with industry best practice.

Visualisation of concepts is a highly important part of the learning process (Tasker & Dalton, 2008), and it has been found that it can be difficult to teach these concepts and processes without visible models upon which the students can base their knowledge. The use of MR brings this visualisation into the real world, and allows the concepts to be explored within a familiar environment.

The use of MR in medical training (Cowling & Birt, 2018) found that student outcomes and skill development was enhanced by the MR simulation. However, the article also stresses the importance of “pedagogy before technology”, meaning that placing the training experience offered ahead of the technology used was vital in ensuring the training provided was worthwhile.

1.2 Serious games in the construction industry

Some prior work has been carried out into the viability of a cyber-physical gaming system in the construction industry (Sivanathan, et al., 2014). The system devised was a ladder climbing activity. By attaching sensors to the participant, it was possible to monitor the movements and posture of the activity. The system scored users depending upon how successfully users maintain a safe biomechanical posture during a ladder climbing activity. Another advantage of this style of cyber physical system was the instantaneous feedback, represented in a virtual form. It was found that such a system enhanced the quality and delivery of training.

This system has influenced the development of the MR VET game, with the aim of providing real time feedback as well as meaningful feedback after the operation has been completed. Future work for this project includes attaching sensors to the participant and grinder for further analysis purposes.

1.3 Gamified Lesson Planning - Wrapping digital pedagogy

Gamified lesson planning is a major outcome of the BEACONING program (Morini, et al., 2015). Successful TVET depends largely on experience, and hands-on experience is vital to successful learning. A gamified lesson can be used to show competency and knowledge transfer in the ability to apply material that has been learned in the classroom. To this end, it is important to ensure the game has been mapped around achieving a set of primary objectives. The game should not be an aside to the main pedagogy, instead it is one of the steps to a learning outcome.

2. MR VET Game

The HoloLens application makes use of CPS and Human-in-Loop (HIL) to provide an immersive MR learning experience that reflects real world working conditions as much as possible. To achieve this, the game makes use of image-based tracking and gesture control. To ensure the game is a useful learning tool, it has been developed within guidelines for TVET from National Occupational Standards (UK).

2.1 Game flow

The game flow is illustrated in Figure 1.

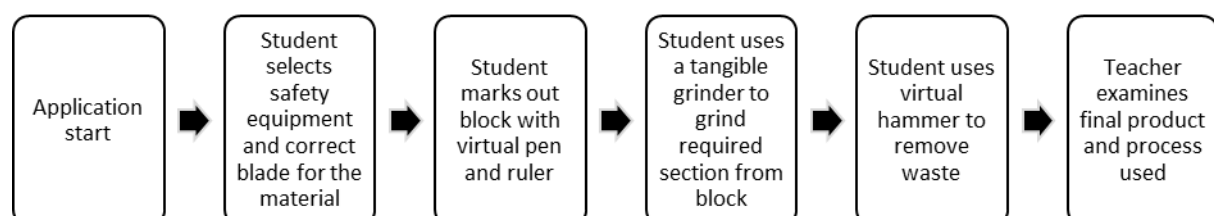


Figure 1: Game flow diagram

2.1.1 Game mapping

The VET game is mapped to National Occupational Standards COSVR195 (National Occupational Standards, 2017). This is outlined in Table 1 and Figure 2.

Table 1: Mapping to Occupational Standards

Participants	Location(s)	Resources	Evidence	Rewards
Students	Anywhere	Mixed Reality, CPS	COSVR195 P1-P6, K1-K16	Experience with an angle grinder, increased employability

COSVR195 Produce standard architectural stone enrichments	
Performance criteria <i>You must be able to:</i>	Performance Criteria 3 Selection of resources K9 the characteristics, quality, uses, sustainability, limitations and defects associated with the resources and how defects should be rectified K10 how the resources should be used and how any problems associated with the resources are reported K11 the organisational procedures to select resources , why they have been developed and how they are used K12 the hazards associated with the resources and methods of work and how they are overcome
Knowledge and understanding <i>You need to know and understand:</i>	Performance Criteria 4 Minimise the risk of damage K13 how to protect work from damage and the purpose of protection K14 why disposal of waste should be carried out safely and how it is achieved
Performance Criteria 1 Interpretation of information K1 the organisational procedures developed to report and rectify inappropriate information and unsuitable resources , and how they are implemented K2 the types of information , their source and how they are interpreted K3 the organisational procedures to solve problems with the information and why it is important they are followed	Performance Criteria 5 Meet the contract specification K15 how methods of work , to meet the specification, are carried out and problems reported K16 how maintenance of tools and equipment is carried out
Performance Criteria 2 Safe work practices K4 the level of understanding operatives must have of information for relevant, current legislation and official guidance and how it is applied K5 how emergencies should be responded to and who should respond K6 the organisational security procedures for tools, equipment and personal belongings K7 what the accident reporting procedures are and who is responsible for making the report K8 why, when and how health and safety control equipment should be used	Performance Criteria 6 Allocated time K17 what the programme is for the work to be carried out in the estimated, allocated time and why deadlines should be kept

Figure 2: COSVR195 - a UK National Occupational Standard for people working in the occupational area of stonemasonry and can be used by operatives, supervisors and managers.

Mapping the application to COSVR195 (Figure 2) ensures it will be a useful tool for the pedagogical aspect of VET. The performance criteria ensure that basic competence is achieved during training, whilst the knowledge and understanding components develop the correct working attitudes. It is important that the VET game reinforces both sections, so the game has been designed around testing as many of these aspects as possible.

2.2 Components of the game

The basis of the game is to replicate a real-life stonecutting operation, using a real angle grinder on a virtual stone block, to provide a training experience that cannot be obtained through purely theoretical means. This involves wearing the correct Personal Protective Equipment (PPE), marking out the desired cut with a scribe, and ruler, cutting the block using the grinder and removing the waste with a hammer.

2.2.1 PPE selection



Figure 3: PPE Selection Interface

One of the top priorities with TVET is to instil the proper safety procedures (see P2 in Figure 2). To this end, a simple, image-based checklist is present to ensure all the correct PPE is equipped (respirator, goggles, safety gloves, ear defenders, safety boots and helmet). This is shown in Figure 3.

2.2.2 Tool Selection

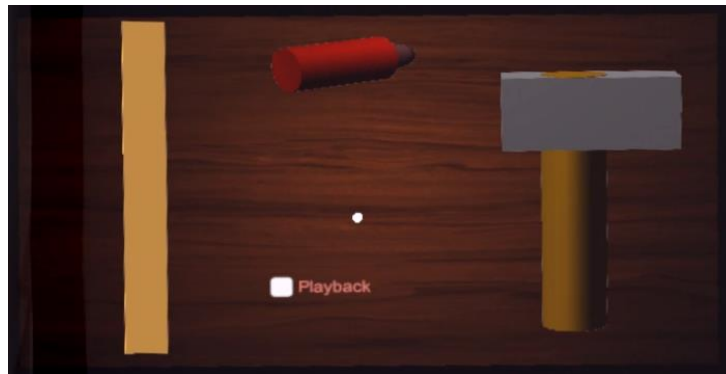


Figure 4: Tool Selection Interface

To ensure that the user will have access to all the required virtual tools (ruler, pen and hammer) with ease, a toolbox is placed in the world space, shown in Figure 4. Selecting a tool from this box will cause it to appear in front of the user. The “Playback” button shows a replay of the cutting process once toggled.

2.2.3 Mission display

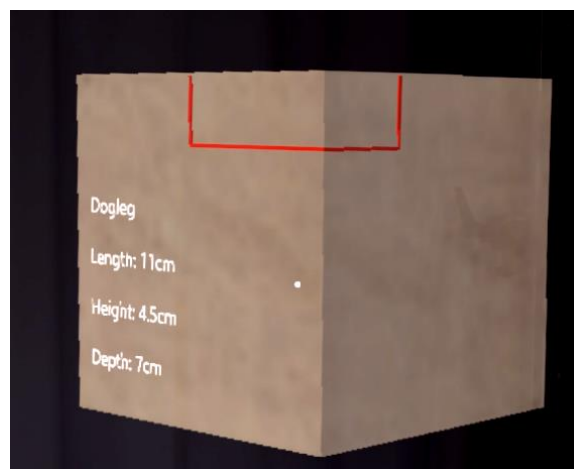


Figure 5: Mission display

The mission display (Figure 5) is a 1:1 representation of the stone block, with dimensional information and the type of shape required.

2.2.4 Marking Out

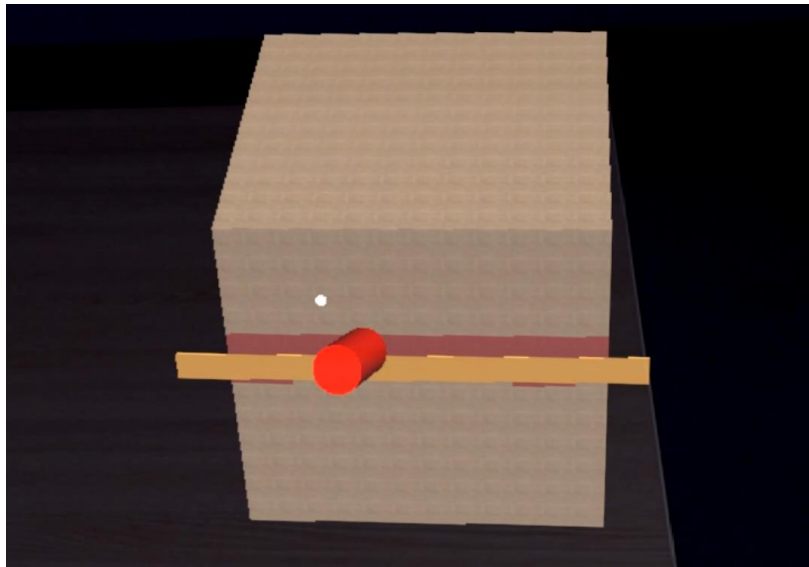


Figure 6: Marking out with a scribe and ruler

As the block is virtual, the marking out of the cut is performed using a virtual scribe and ruler (Figure 6) using HoloLens' gesture controls, demonstrated in Figure 7. The manipulation of these objects are performed using gesture commands. The ruler uses a "tap to place" mechanism whereby once tapped, the ruler follows the user's gaze and "snaps" on to any gazed object. The scribe uses a "hand dragging" mechanism whereby the user gazes at the pen, taps it and manipulates it using their hand. As the scribe and the hand are not actually interfacing, a control-display gain value (Casiez, et al., 2008) is used to approximate the user's hand movements into scribe movements. This builds upon research previously carried out into control-display gain in a mixed reality environment (Harper, et al., 2018).

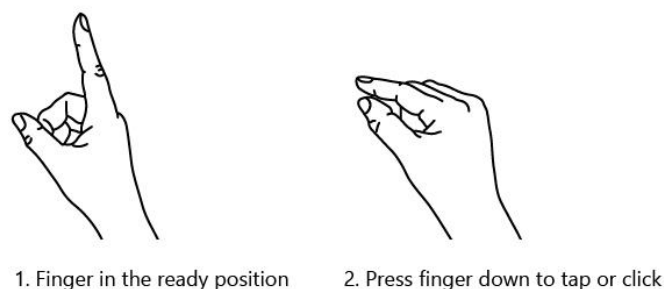


Figure 7: HoloLens gesture commands (Microsoft Corporation, 2018)

2.2.5 Grinding

Using Vuforia's image-based tracking, a tangible grinder is used to cut into the virtual stone block (Figure 8). The image target was trialled in numerous positions, it was determined that placement on top of the blade allowed for the largest operating range before the target disappears from camera view and tracking ceases to operate. Real angle grinding operations produce physical vibration in the grinder, which cannot currently be replicated, however other aspects such as dust and sound are reproduced to provide some tangible feedback to the operator. This is also where the chosen grinding blade comes into effect, as an incorrect choice of blade for the stone will cause the grinder to fail.



Figure 8: Grinder with image target (left) and grinding stone (right)

2.2.6 Waste Removal

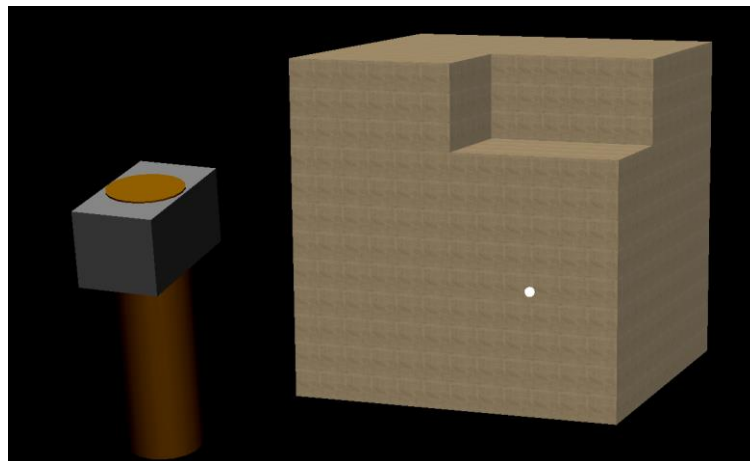


Figure 9: Waste removal with virtual hammer

The final step in the stonecutting process is waste removal. This is simplified in the application to the use of a virtual hammer to remove the cut-out portion of the block (Figure 9). The hammer uses the same “hand dragging” input system as the pen.

2.3 Teacher use

As well as the output of the application, teaching staff have control over the application parameters through the BEACONING service. The teacher can control the type of stone used and the cut required, which is read by a .JSON file in the application. The application tracks parameters of the usage and stores them in another .JSON file. This file can then be opened in the BEACONING service, allowing the teacher to analyse the placement of the cut, as well as the usage of safety equipment. It is also possible to record a replay of the session for teacher playback.

2.4 Implementation

As previously mentioned, the Microsoft HoloLens was chosen as the operating device for this application. It has unique advantages that have been utilised in this study. The main advantage for operation in VET workshops is that it is completely self-contained; no other equipment is required to operate it as all processing and rendering is carried out on the device itself, as opposed to immersive headsets such as the HTC Vive or Oculus Rift. Another key advantage is the onboard cameras, which allow for the image-based tracking, and the translucent screens which allow the holograms to be placed in the real world.

The device runs a modified, 32-bit version of Windows 10, similar to that found on Windows phones, and exclusively uses Universal Windows Platform (UWP) applications. The specifications can be found in Table 2.

Storage	64GB Flash
RAM	2GB
CPU	Intel custom 32-bit Atom processor with TPM 2.0 support plus separate Microsoft Holographic Processing Unit (HPU)
Graphics Processor	Intel integrated graphics
Holographic resolution	2.3 million total light points
Field of View	16 degrees
Display resolution	1268 x 720 per eye at 60Hz (240Hz over red, blue and two green layers)
Sensors	1 IMU, 4 environment understanding cameras, 1 depth camera, 1 2MP photo/720p video camera, 4 microphones, 1 ambient light sensor
Connectivity	3.5mm audio jack, Wi-Fi, Micro USB 2.0, Bluetooth 4.1 LE

Table 2: HoloLens specifications

The application was developed on an HP Compaq 8200 Elite CMT PC. The specifications are as follows in Table 3:

CPU	Intel Core i7-2600
Memory	16GB DDR3, 1333MHz
Storage	2 x 500GB HDDs with 4 partitions
GPU	Nvidia Quadro 4000
Operating System	Windows 10 with Fall Creators Update, 64-bit

Table 3: Development PC specifications

The development environment used was Unity 2017.3.1p1, in C#, utilising the Mixed Reality Toolkit provided by Microsoft on GitHub (Microsoft Corporation, 2018) to integrate HoloLens specific functionality. The Vuforia plugin was included to perform the image based tracking for the grinder. The applications are built on the PC and deployed to the HoloLens over a LAN connection. Unity was chosen for the development process due to its ability to produce 32-bit UWP applications, as well as its ease-of-use, extensive documentation, and support for the HoloLens and Vuforia.

3. Findings

It is challenging to quantify the effectiveness of training without resorting to subjective measures such as questionnaires. To acquire data on the use of a TVET game, a focus test was carried out at Glasgow College. These involved students and their teachers making use of both the computer-based TVET game and a prototype MR version. From these tests, the participants were asked to complete a simple check cut in the computer game and given no further instruction, to gauge the quality of the in-app instructions and the intuitive-ness of the controls and interface. After completing this task, a standard BEACONING questionnaire was filled out and the results collated.

3.1 Questionnaire Results

The survey was carried out with a class of eight second year Stonemasonry students, and a separate one with four teachers was also performed. The questions asked to students that were relevant to the TVET game were as follows:

1. What styles of games the students would want to play in a class (co-operative, competitive, quizzes, etc.)
2. Difficulty rating of the game.
3. Level of excitement generated by the game.
4. How much various aspects of gamification motivated them to carry out their tasks (leaderboards, progress bars, classroom comparisons, etc.).
5. How much various aspects of gamification would motivate them to carry out their tasks in STEM subjects
6. What feedback was expected from the game.

From the student questionnaire, it was found that most students would like to play simulation type games in class. Feedback on difficulty was split exactly in half between the game being at a suitable level of difficulty and being too easy. The consensus on excitement was that the game was neutral, neither generating excitement or boring. In terms of motivation in the game, results indicated that the most motivating factor would be the rewards for completion, which potentially include course credits. Motivation for STEM subjects showed that the subject of the lesson was the most motivating factor, along with the inclusion of minigames. Finally, the most valuable feedback expected from the game was reasons for why any answers given were correct or incorrect.

The teachers survey contained the following relevant questions:

1. What components of a lesson plan need to be adjustable (difficulty, length, etc.)
2. How to tailor the lessons towards students with special needs
3. What data to consider for student assessment
4. If they think the students enjoyed playing the TVET game

In terms of adjustable components, the teaching staff unanimously wanted control over the length and difficulty of the game. For tailoring to special needs students, again the difficulty was unanimously requested along with specially formulated task descriptions. For student assessment purposes, the teaching staff unanimously requested access to the number of attempts made and the difficulty of the task. Finally, the teaching staff unanimously “strongly agreed” that the students enjoyed the gamified lesson.

3.2 Discussion of Results

Acquiring feedback from both student and teacher points has allowed for a useful comparison between what the students think is important, and what the teachers want the students to do. Despite these results being generated from a questionnaire focussed on the desktop VET game, as there are common points across the desktop and MR based games it is still possible to gain some useful insight from these surveys.

Some of the feedback generated from the questionnaires was a reassurance that TVET in a gamified environment is possible and what the students and teachers want to see. Staff agreed that students enjoyed

the lesson, and students showed interest in the simulation type of game that was on offer, and that it related to their course content.

Difficulty was a repeating point raised, by both teachers and students. To this end, it is important for the TVET game to have a mission selection of some variety, and this has been implemented currently in the form of a choice of stone and premade cuts, and in future a choice of cut shape and depth will also be implemented. It would be possible for different students to run different levels of difficulty, as the mission selected is recorded in the .JSON file output from the application.

At the time of the on-site test, the MR app was still in a prototype stage, with no support for a tangible grinder and some interface and performance issues, so only anecdotal feedback was taken for further application development. This led to the creation of the toolbox for tool selection, the free placement and rotation of the block and the simplifying of gesture controls in the game. Further testing is to be carried out very shortly with the current, improved version of the application, complete with image-based tracking.

4. Future Work

To make the application fully viable for public use, some further work will be required. The main issues with the application in its current state are: usefulness of results, grinder tracking, and rendering performance.

As is, the results are images of the cuts, an on-device replay, and a checklist of safety equipment and blade used. Images of the marking out should also be taken. The replay should either be viewable on other devices (such as a PC) or saved to the device for later viewing. This could involve the use of a proxy application on a PC to allow free camera movement and pause functionality to analyse the procedure used by the student. For quick reference amongst a class of students, it would be useful to have a sort of scoring functionality for the quality of the marking and cut in comparison to the mission that was provided.

Whilst Vuforia's image tracking is effective for horizontal cuts, it can prove impractical for vertical cuts due to the requirement of keeping the image target within camera shot. The solution for this will be to implement CPS, for example accelerometers connected to the grinder, which are connected over TCP to the HoloLens. Interpreting the output from the accelerometer will allow for cutting even at angles where the blade is not visible.

Another issue with the application is one of performance, namely the frames per second (FPS) output by the device. As the application uses a "voxel" system to allow for cuts and drawing on the surface (the stone block is made up of hundreds of smaller cubes), the FPS will drop from the optimal 60FPS target when the block is in view, as the application becomes GPU-bound. One solution for this is the use of a façade block, with the voxels hidden and not rendered within, only to be rendered when the hammer strikes the block to remove material. This reduces the rendering load of the application, increasing the FPS performance towards the target.

5. Conclusions

This study shows the use of a Mixed Reality system to deliver a novel vocational educational training application for stonecutters, building upon the previously produced desktop game. The use of a real stone grinder is positive from the aspects of pedagogy and health and safety, as proper handling can be instilled before day-to-day use in industry. Ensuring the TVET pedagogy is carried out in a real-world environment increases the pedagogical aspect of the application, by allowing visualisation of the concepts learned in class. Collaborating with further education institutions has allowed for implementation of features that the teachers and students want to see. Mapping the application to National Occupational Standards also ensures the game has real learning value, for both operational competency and safety.

5.1 Acknowledgments

The work presented herein is partially funded under the European H2020 Programme BEACONING project, Grant Agreement nr. 687676.

6. References

Casiez, G., Vogel, D., Balakrishnan, R. & Cockburn, A., 2008. The Impact of Control-Display Gain on User Performance in Pointing Tasks. In: *Human-Computer Interaction*. London: Taylor & Francis, pp. 215-250.

Cowling, M. & Birt, J., 2018. Pedagogy before Technology: A Design-Based Research Approach to Enhancing Skills Development in Paramedic Science Using Mixed Reality. *Information (Switzerland)*, 9(2).

Harper, S. et al., 2018. *Control-Display affordances in simulation based education*. Québec City, American Society of Mechanical Engineers.

Microsoft Corporation, 2018. *Microsoft/MixedRealityToolkit-Unity*. [Online] Available at: <https://github.com/Microsoft/MixedRealityToolkit-Unity>

Morini, L., Arnab, S. & Loizou, M., 2015. *4.8 Gamified Lesson Plans*, Paris: BEACONING.

National Occupational Standards, 2017. *Produce standard architectural stone enrichments*, s.l.: Scottish Social Service Council.

Sivanathan, A., Abdel-Wahab, M., Bosche, F. & Lim, T., 2014. *Towards a Cyber-Physical Gaming System for Training in the Construction and Engineering Industry*. Buffalo, American Society of Mechanical Engineers.

Tasker, R. & Dalton, R., 2008. Visualizing the Molecular World – Design, Evaluation, and Use of Animations. *Visualization: Theory and Practice in Science Education*, Volume 3, pp. 103-131.