Some pedagogical observations on using augmented reality in a vocational practicum

British Journal of Educational Technology 51 (3), pp 645–656, 2020
doi:10.1111/bjet.12901
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Abstract

The use of augmented reality (AR) in vocational education and training can still be considered as being in its infancy, although interest in it is growing in response both to its potential for teaching and its adoption as a practical tool in various industry sectors. One example of early-stage AR use is illustrated from a practicum for training apprentices in the chemical industry; this involves the use of various AR objects for learning a simple production operation. Although this application had been conceived of purely in terms of substitution for existing instructional methods, it also gave learners greater control of the learning process and created opportunities for collaborative learning. Pedagogically, AR can be considered as a mildly disruptive technology that favours learner-managed learning, a factor that is aligned with its ability to support localised decision-making in industry.

Key words
Augmented reality; vocational education and training; practicum; chemical industry.

This is a manuscript version of the article as accepted for publication and page numbering will differ from that in the journal, which can be found here:

https://bera-journals.onlinelibrary.wiley.com/doi/epdf/10.1111/bjet.12901

Structured practitioner notes

What is already known about this topic

- Augmented reality (AR) tends to favour exploratory, learner-managed and, increasingly, collaborative learning
- Evaluations of AR for vocational learning are on balance positive, with improved understanding, fewer errors and faster task completion or improved learning performance all reported
- AR is still in the early stages of adoption in vocational education and training (VET), with trials and small-scale applications dominating.

What this paper adds

- Introducing AR even for simple learning tasks affects the pedagogical approaches that are used
- Effects include greater learner control of the learning process and encouragement of reflection-in-action.

Implications for practice and/or policy

- AR is a mildly disruptive technology that needs to be considered in terms of its pedagogical implications as well as its effectiveness as a learning tool
- The directions favoured by AR in education and training appear consistent with changing skill and learning demands in industry.

Introduction

Augmented reality (AR) involves "blending… data — information, rich media, and even live action — with what we see in the real world… to enhance the information we can perceive with our senses" (Johnson et al*.,* 2010, p16). At a basic level this simply involves an overlay of digital information that relates to a location or context, such as data relating to an industrial operation or text and graphics interpreting a historic site. More complex applications make use of live three-dimensional scanning, enabling the automatic positioning of virtual objects in the real environment; this provides some of the characteristics of a virtual reality simulation, while allowing the user to be still fully aware of their surroundings. Although the term 'augmented reality' does not appear to have been coined until the early 1990s, simple forms of AR have existed since the 1960s (Lee, 2012), and AR has been used to a small extent in education for over two decades. However, its use for work-related training was initially largely limited to military, corporate and university-level professional environments, with cost preventing its uptake in vocational education and training (VET) establishments. More recently, the availability of AR applications on smartphones, tablets and laptops, increasing affordability of AR glasses, and more straightforward programming, are facilitating its adoption in VET.

AR has been noted as lending itself to experiential and exploratory forms of learning, in particular by requiring learners to engage with real-world surroundings as well as with instructional or explanatory material (Miller and Dousay, 2015; Nawaz, Kundu and Sattar*,* 2017). AR can be used in other ways, for instance to provide direct instruction and to complement and extend instructional materials, but its essential feature is that unlike virtual reality (VR) it requires a physically real environment on which it is overlaid and within which attention is maintained (Richey 2018). In VET contexts this environment is generally either the workplace itself, or a contained or physically simulated version of the workplace, in which learners develop their skills and understanding through demonstration, coaching and practice (a 'practicum', Schön [1987]). Teaching in VET is however generally geared to work-focused ends, meaning that the scope for using AR for more open-ended exploratory learning is less obvious at least until learners have achieved a basic level of mastery.

This paper examines the use of AR in a small-scale pilot with apprentices in a practicum environment (a chemical industry training establishment in eastern Germany), exploring the impacts on learning and training design.

Augmented reality in vocational education and training

The VET sector is a difficult one to define, in many countries simply absorbing everything that doesn't fit into general (school) and higher (university or equivalent) education. Added complications are introduced by some countries' VET systems overlapping with (and including parts of) higher education, while others are restricted to secondary-level education (i.e. European level 4 and below) and are sometimes seen as part of the secondary sector. Secondary-level VET in particular has been described as primarily instrumental and technocratic, and geared to the development of occupationally-oriented knowledge and competence rather than more general intellectual and social capabilities (e.g. Wellington, 1993; Moodie, 2002). Although the sector is much broader than this might suggest (Stanton, Morris and Norrington, 2015; Hippach-Schneider and Huismann, 2016), much of its activity is nevertheless concerned with teaching skills, know-how and associated principles.

The last decade or so has seen increasing uptake of both AR and VR in VET. VR lends itself particularly well to conceptual learning, simulations including of potentially hazardous situations, and to some physical skills (for instance in an early example of haptic VR in vocational training, Porter et al. [2006] report on its use for training welders, reducing the waste inherent in practising on real materials). AR has certain advantages over VR for use in a hands-on practicum through presenting information and digital objects alongside the physical environment, and when relevant enabling learners to interact directly rather than within the technology. Nevertheless, in VET it has taken longer to be fully exploited because of factors such as the need for more advanced equipment, ensuring health and safety, integrating effectively with practice activities, and gaining acceptance from teachers and trainers. As an example of the present extent of adoption, a recent study of 42 German providers and companies using VR or AR for training (Osmers, Blunk and Prilla*,* 2019) mapped current use against five steps drawing on the capability maturity model developed by Paulk et al. (1993): 39% were at stage 1 (initial piloting), 41% at stage 2 (occasional or localised use), and 20% at stage 3 (regular use with defined processes); none had reached stage 4 (integration into the organisation's systems and processes) or beyond.

AR has particular advantages for low-risk physical tasks such as assembly, maintenance and control operations, as it allows the learner or operator to work in the physical environment while having access to real-time information, virtual models and guidance. Applications that have been reported to date include aeronautic maintenance (Rios et al*.,* 2011), industrial assembly and service operations (Gavish et al., 2015), railway safety (Kaul and Smith, 2018), and industrial assembly operations, product customisation, safety inspection, and computer-aided design (Bottani and Vignali, 2019). In the study by Osmers et al. (2019), AR training applications include chemical operations, mechanised production, housekeeping, logistics operations, painting, ship maintenance, automotive repair and port operations. The principal features or affordances of AR indicated in these studies are:

- providing simple overlays, background information and schematics to inform the completion of tasks;
- providing conceptual information as an interactive overlay on the real-world environment, for instance to show forces, currents and flows;
- providing more complex, interactive overlays, for instance showing properties or processes inside closed spaces;
- enabling error recognition and correction procedures to be introduced;
- providing contextual guidance, which may be adaptive (Bell and Kozlowski, 2002), to aid the development of skills;
- enabling remote interaction, for instance to allow a distant trainer to see what a learner is doing and provide instant guidance and feedback (Hofmann, 2018).

Evaluations in particular vocational contexts such as those of Rios et al. (2011) and Gavish et al. (2015) as noted previously, as well as meta-analyses of applications across education generally (Bacca et al., 2014; Ozdemir et al., 2018; Garzón and Acevedo, 2019), indicate that there can be significant advantages to AR over both unaugmented training and, in specific contexts, other technology-facilitated methods such as VR and multimedia. These include fewer errors and misunderstandings; better-developed understanding, including in terms of how to apply knowledge effectively in practice situations; and improved overall learning, as evidenced by test performance or progress by the end of the session. AR is also reported as able to improve learner motivation, particularly in the dimensions of attention and confidence (Bacca et al., 2019). On the other hand cases are reported where learning is slower using AR, due to the need to first learn how to use the technology or work with the specific learning scenario, and to a lesser extent to technical problems encountered during use.

Introducing augmented reality in a chemical operations practicum

To date, industrial uptake of AR has been led by the manufacturing, machine tool, aeronautical and automotive industries (Bottani and Vignali, 2019). Use in the chemical industry is not as well developed, though increasing; applications include providing diagrammatic overlays for maintenance engineers (Boccaccio et al., 2018) and allowing interaction between an operator and a remote expert, for instance to diagnose faults or aid inspection (Duong and Gravdal, 2018). SBG Dresden (see below) also reports that the need in chemical plants for an increasing number of parameters to be measured and controlled is leading to interest in real-time AR-based visualisation from the shop floor, enabling operators to make local decisions without needing to refer to the plant's control centre. In relation to the formal training of chemical operators, the German federal vocational training agency Bundesinstitut für Berufsbildung (BIBB) approved in 2018, as part of its 'Berufsbildung 4.0' strategy (Esser et al., 2016), an elective module on digitalisation and connected production. This is designed both to provide training in the use of emerging digital technologies, and to encourage their use as teaching tools.

SBG Dresden is an inter-company training centre for the chemical and pharmaceutical industry in eastern Germany. Its provision spans school-leaver apprenticeships through to the level 6 Meister qualification, which is designed to support progression to operational manager positions. In relation to the German dual VET system, the centre provides practical training additional to that received at work, as opposed to the more theoretical off-job component which is provided by a vocational school. Level 4 apprentices such as chemical operators are trained in the centre's chemical plant, with the aim of providing relevant practical know-how (*Handlungswissen*) along with, particularly for second- and third-year apprentices, critical thinking skills relevant to practical tasks. The centre's facilities can be regarded as a practicum, with a plant where chemical operations are scaled up by a factor of 10 to 20 compared with what would be encountered in a laboratory.

In response to changes in industry and in preparation for introducing the new training module, SBG has recently introduced elements of AR into the practicum environment on a pilot basis. Hofmann (2018) describes a small-scale trial using AR glasses (Microsoft HoloLens programmer version) for remote one-to-one coaching on chemical operations, along with the development of a short trainer-training programme to induct trainers into the use of AR. Further mini-trials followed using additional scenarios and approaches to using AR; one of these is described below. For these initial trials the AR applications were kept relatively simple, relating to short sequences of hands-on learning. One immediate, practical finding was the need to maintain both hands free for operational and safety reasons, which has favoured the use of smart glasses rather than tablets or other portable devices, consistent with findings in the industry (Duong and Gravdal, 2018). In the future it is intended that these will be developed as safety glasses for use in combination with protective helmets.

The use-case: setting up a screw extruder

One of the trials carried out at SBG concerned training chemical operations apprentices to use a screw extruder (Brabender PlastiCorder), a machine that extrudes plastics and similar materials for various purposes in the chemical and lacquer industries. Eight physical steps are required to set up and start the extruder (Table 1), then production is controlled via a computer interface. Each individual operation is simple, but the steps must be carried out correctly and in the right order otherwise an error condition will be triggered and the machine will fail to operate.

Table 1. Operations to start the extruder.

Step	Description	Notes
1	Open water supply and thermostat	Two valves, any order
2	Switch on main power supply	On/off
3	Switch on and start machine	Two switches in sequence
4	Turn mode switch to correct position	Two options
5	Start temperature control	On/off
6	Start thermostat and heating	Four possible positions, one correct
7	Start conveyor belt	Two switches each to the correct position (one of two), one switch on/off
8	Change to 'REM' and confirm by pressing start	Two buttons in sequence; the extruder can now be controlled from the computer screen

Practical teaching at SBG generally follows the principles of cognitive apprenticeship, developed in the 1980s by Collins and colleagues (Collins, Brown and Newman, 1989; Collins, 2005) as a method for applying pedagogic principles from traditional apprenticeships (e.g. Lave, 1988) into formal learning environments. Its approach draws in part on situated learning theory (Lave and Wenger, 1991). The core processes of cognitive apprenticeship teaching consist of *modelling*, where the trainer or expert carries out the task or process, observed by learners; *coaching*, where the learners carry out the task, with the trainer observing, offering hints, answering questions and giving feedback; and *scaffolding*, where specific resources are provided to aid learning, with the aim that learners become progressively less dependent on them (*fading*). More advanced stages comprise *articulation*, where learners are asked to state their knowledge in order to help refine their understanding; *reflection*, including learners replaying, analysing and critiquing the learning episode, and comparing their approach and performance with those of the expert; and finally *exploration*, where learners frame and solve problems on their own. In the context of the extruder, the trainer begins by describing how the machine works and the steps needed to operate it, checking the learner's understanding (modelling). This is followed by the learner carrying out the tasks with support from the trainer and reference to working instructions (coaching and scaffolding). As the learner becomes more confident, the trainer intervenes only if necessary (fading). There is no explicit articulation and assessment stage, but the trainer will check that the learner is able to set the machine up correctly. Trainers and apprentices report typical practice times to reach a proficient level as between 20 and 30 minutes, sometimes up to 40.

Training on the screw extruder was selected for trialling with AR due to the self-contained nature of the overall task, the potential to help learners gain a robust mental model of how the machine works, and the potential to minimise errors and speed up the time to proficiency. Successful examples of using AR have been documented for training in manufacturing and repair processes (Azuma, 1997) and in assembly and servicing operations (Gavish et al., 2015; Wang, Ong and Nee, 2016). While these applications differ in detail from setting up and operating machinery, all involve a sequence of discrete steps for the manipulation of physical objects, and there are enough similarities to suggest that a simple AR application should be able to aid training in preparing the extruder. To take this forward, digital objects were developed (a) to demonstrate how the extruder is operated from a user perspective, and (b) to illustrate its internal workings and the need to maintain a consistent temperature gradient. In order to aid rapid learning, the AR representation was designed according to two principles: firstly, to focus on the sequence of operations needed to reach the end-goal rather than providing more complex explanations at each stage (Baber and Stanton, 2002); and secondly, to maintain a high degree of physical fidelity (Allen, Hays and Buffardi, 1986), so that the correct components of the machine would be quickly recognisable. For illustrating the start-up operations, a set of digital images and short videos (a few seconds each) were made (figure 1); these are viewed through the AR glasses, directly alongside or superimposed on the relevant part of the machine. A virtual representation ('digital twin') of the extruder was also made (figure 2), with additional information superimposed to illustrate the working of various parts; the main requirement here was for functional fidelity (ibid.), although accurate physical representation was maintained where possible. This allowed learners to explore the internal operation, in particular showing them the functioning of the screw and the effect of different temperature adjustments.

Programming was carried out using Unity software. The most time-consuming part of the task was making the digital depiction of the extruder and physically realistic representations of moving parts, and development time was kept down by simplifying the digital representation, particularly where an equivalent or more effective job could be done using the videos. In the absence of a programmer on

SBG's staff, costs were minimised by bringing in an IT student from Technische Universität Dresden via a European Union-funded project, working approximately two days a week over a two-month period; at standard EU project rates this would cost just under 4,000 euros, 20% or less of the cost of engaging a professional programmer. In either case, given that the AR materials can be expected to remain in use for the lifespan of the particular model of extruder, there is potential for the development costs to be recouped via the substantially reduced need for trainer input and (more tentatively) the scope for shortening the training sessions.

Schritt 7: Auf "Rem" umschalten
und danach "Start" bestätigen

Figure 1.
Screen-shot from AR-based instructional video.

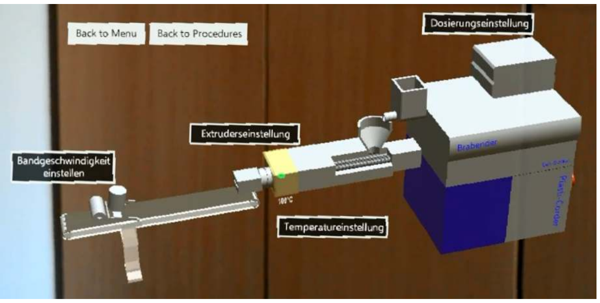

Figure 2.
Digital representation of the extruder.

In February 2019 one group of three apprentices (the normal number for training on the extruder) was selected to take part in the AR trial. Two had worked with the machine two weeks previously, while the third was new to it (groups typically have mixed experience of tasks, as apprentices at the same stage of their programme but from different companies can come into the centre at different times). In order to ensure that learning took place without external support, the role of the trainer was limited to providing instruction on the AR equipment (Microsoft HoloLens). The apprentices each had a brief introduction on how to work with the AR glasses. The apprentices then spent approximately ten minutes interacting with the visualisation of the extruder. The 'novice' was chosen to start the machine, supported by the visualisation and the other two apprentices. After watching each simulation, he went through the relevant part of the start-up and adjustment process. Towards the end of the process, an error simulation was introduced where the temperature in the machine became out of balance, producing an error signal on the computer. Using knowledge of how the machine functions gained from exploring the AR model, the apprentice was able to react to the error and control the temperature effectively. The only further intervention by the trainer was to check that the machine had been set up correctly. A repeat of the trial was carried out in October, with four further apprentices (three with previous experience of using the machine, and one new to it), with similar results.

Figure 3.
Working with the extruder.

Following the exercise, apprentices from both groups completed a standard form assessing the learning transfer at each step of the process, rated according to a three-point scale (yes, partly, no). 87% of scores were allocated to 'yes', i.e. fully transferred. Apart from some problems reported with the physical machine (steps not being available to carry out), the only comment about the AR representation was that in the visualisation, the hints were presented too quickly. The second group also completed an evaluation form focusing on the learning process, self-assessment of their skills and understanding, and use of the technology, using a five-point Likert scale. 89% of the scores throughout were either 'very much' or 'yes'. There was slightly less confidence about being able to apply the learning in-company (equally split between 'yes' and 'a little'), and one apprentice who wanted to learn more about the extruder couldn't find answers to his questions. One apprentice commented that the AR glasses were frustrating to use, and another added a suggestion for showing an additional part of the machine.

This scenario proved effective in several ways. It enabled the learners to arrive at a common understanding of the machine from their different starting-points. It also appeared to enable the apprentices to create a mental model of how the extruder worked, rather than regarding it as a 'black box'; this was instrumental in enabling quick and effective reaction to the fault condition. With one exception (23 minutes), time to proficiency was reduced to between 8 and 11 minutes, i.e. after exploring the AR representations the apprentices could set the machine up without further support. The extruder session is scheduled to become one of the scenarios where AR-based training will be used as standard at SBG. A limitation to date has been the availability of affordable, relevant AR equipment (for the reasons described previously this has meant AR glasses rather than cheaper alternatives), along with bespoke programming. Further AR applications will also be developed ready to introduce the digitisation elective for chemical operators in 2020/21.

Discussion

The case described above represents a small-scale exploration of using a simple AR application for developing a specific task skill in a vocational learning environment. Following Puentedura's SAMR (substitution – augmentation – modification – redefinition) model (Hamilton, Rosenberg and Akcaoglu, 2016), the aim of introducing AR was principally one of substitution for existing methods, with some expectation of augmentation in the form of improved learning efficiency. As described above, there is evidence of increased efficiency in the form of the time taken to reach a proficient level, with some indication – though not evidenced directly – of improved mental modelling. Improved learning performance is consistent with other recent studies of AR in education and training. Sirakaya and Kilik Cakmak (2018) for instance found that in a controlled experiment involving the introduction of AR-mediated methods to secondary school classes, overall learning achievement was improved and misconceptions substantially reduced. Similarly, a meta-analysis of 16 studies by Ozdemir et al. (2018) found that use of AR correlated with higher learning achievement, with a stronger effect for natural sciences than social sciences; the latter was posited as due to the ability to concretise and represent abstract concepts more easily in the natural sciences, something that can also be expected to apply to representations of processes in technical fields. The study of assembly operations by Gavish et al. (2015) reported better learning performance, but also a slight increase in the time taken; in the example here, the majority of learners found the AR technology easy to use, and the time taken for familiarisation was easily outweighed by more rapid learning of the content material. Improved mental modelling is supported by studies by Omar et al. (2019) and Nuanmeesri (2018), both of which found that the use of AR enabled more effective visualisation; to confirm whether this is the case here, a stage of articulation and reflection could be used following the completion of the operations.

Returning to the SAMR model, the extruder task itself offers little or no scope for modification or redefinition, but introducing AR has facilitated a pedagogical change from a trainer-led model to one that is primarily self-managed and to an extent collaborative. The modelling stage moves from following a description by the trainer to use of the AR objects, enabling in particular a visual understanding of the internal workings of the machine rather than relying on description. Scaffolding moves from trainer support and paper-based instructions to the AR-based images and mini-videos, which are controlled by the learner. Perhaps most importantly, a separate demonstration phase becomes unnecessary, with learners able to follow the AR instructions directly to learn to use the machine, with support where needed from peers. The learning process using AR shows greater evidence of reflection-in-action (Schön, 1987) and self-pacing, with learners checking their understanding at each step before proceeding to the next. A next step (following Schön, 1987 and Collins, 2005) is to add a further stage of reflective discussion to consolidate and extend learning, though this may be more effective after completing the full sequence of training on the extruder, i.e. including the screen-based operations.

Discussions of AR-based education and training (e.g. Cochrane et al*.*, 2014; Miller and Dousay, 2015; Green, 2017; and Ozdamli and Hursen, 2017) indicate that, other things being equal, AR favours forms of learning that are experiential, reflective, and self-directed or self-managed. This is supported by the extruder trial, which although it is very small in scale is of interest because it involves learning a specific and tightly sequenced task skill. The scenario raises the questions of whether the same learning design could be achieved without using AR, and to what extent the design is a corollary of introducing the technology. In principle the same set of objects could be presented in a different way, for instance through videos and animated schematics on the same screen that is used for the latter stages of operating the machine. In practice this would necessitate the learner having to move back and forth between the screen and the various switches and valves in the working area, and whether this has an effect on the efficacy and efficiency of learning would need to be explored. For the second question, a design could be envisaged where the instructor directs the use of the AR and provides coaching instead of or in addition to peer interaction, although simply to treat the AR objects as visual aids for instruction results in duplication. What can be said is that making efficient use of AR, consistent also with aiming to maximise return on investment, tends to favour self-managed learning.

Conclusions

The emphasis to date in the literature on using augmented reality in vocational contexts is principally on matters of technical implementation and on its effectiveness in supporting the achievement of learning aims. There is already a substantial body of evidence in support of AR as a learning tool for VET, although there is room for more research to inform its applicability in different contexts, aid good practice in learning design, and provide longer-term evaluations particularly of learners' subsequent effectiveness in the workplace and propensity to learn independently from practice. The case-study described here could be usefully extended to this end, both quantitatively and in terms of exploring apprentices' subsequent confidence and competence; in any similar exercise it would also be valuable to capture comparable data from the learning process before the introduction of AR. The ability of AR to support learner-managed and collaborative learning is also becoming widely recognised, though this appears to be a factor that is given less emphasis in VET than in general and higher education. On balance, AR can still be considered in its infancy in VET, with, as Osmers et al. (2019) indicate, some way to go before it becomes part of mainstream vocational pedagogy.

The case examined here suggests that introducing AR, at least in forms other than providing straightforward data overlays, tends to create changes in training methods that go beyond what is necessarily intended. This appears particularly so if the intention is to use AR as a straightforward substitute for direct instruction, where it favours greater self-management of learning by the learner; even in task-oriented settings AR appears to encourage self-managed learning, self-pacing and reflection. Augmented reality can therefore be considered to be a mildly disruptive technology when introduced in VET environments, at least in terms of the styles of teaching and learning that it promotes. This does however appear consistent with day-to-day learning and skills demands being created by the introduction of AR and other new technologies in industry, and therefore something that VET needs to explore and embrace.

Statement on conflicts of interest, ethics and open data

The authors have no conflicts of interest to report. There are no research ethics bodies in the authors' organisations; the external author has examined the use-case for potential ethical issues. A summary of learner feedback is provided at http://devmts.org.uk/ARVETdata.pdf

References

Allen, J., Hays, R., and Buffardi, L. (1986). Maintenance training simulator fidelity and individual differences in transfer of training. *Human Factors, 28* (5), 497-509.

Azuma, R. (1997). A survey of augmented reality. *Presence: Teleoperators and virtual environments, 6* (4), 355-385.

Baber, C. and Stanton, N. (2002). Task analysis for error identification: theory, method and validation. *Theoretical Issues in Ergonomics Science, 3* (2), 212-227.

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., and Kinshuk (2014). Augmented reality trends in education: a systematic review of research and applications. *Educational Technology and Society, 17* (4), 133-149.

Bacca, J., Baldiris, S., Fabregat, R., and Kinshuk (2019). Framework for designing motivational augmented reality applications in vocational education and training. *Australasian Journal of Educational Technology, 35* (3), 102-117.

Bell, B., and Kozlowski, S. (2002). Adaptive guidance: enhancing self-regulation, knowledge and performance in technology-based training. *Personnel Psychology, 55* (2), 321-331.

Boccaccio, A., Cascella, G., Fiorentino, M., Gattullo, M., Manghisi, V., Monno, G. and Uva, A. (2018). Exploiting augmented reality to display technical information on Industry 4.0 P&ID. In F. Cavas-Martinez, B. Eynard, F. Fernández-Cañavate, D. Fernández-Pacheco, P. Morer and V. Nigrelli (Eds.), *Advances on Mechanics, Design, Engineering and Manufacturing* (pp. 282-291). Cham, Switzerland: Springer.

Bottani, E., and Vignali, G. (2019). Augmented reality technology in the manufacturing industry: a review of the last decade. *IISE Transactions*, *51* (3), 284-310.

Cochrane, T., Antonczak, L., Keegan, H., and Narayan, V. (2014). Riding the wave of BYOD: developing a framework for creative pedagogies. *Research in Learning Technology, 22*, 24637.

Collins, A. (2005). Cognitive apprenticeship. In R. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 47-60). Cambridge, UK: Cambridge University Press.

Collins, A., Brown, J. and Newman, S. (1989). Cognitive apprenticeship: teaching the craft of reading, writing and mathematics. In L. Resnick (Ed.), *Knowing, learning and instruction: essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Duong, K. and Gravdal, K. (2018). *Knowledge-sharing with augmented reality – a single case-study of remote assistance in a chemical production plant.* Trondheim, Norway: Norwegian University of Science and Technology.

Esser, F., Helmrich, R., Härtel, M., Padur, T. and Zinke, G. (2016). *Berufsbildung 4.0 – Fachkräftequalifikationen und Kompetenzen für die digitalisierte Arbeit von morgen*. Bonn, Germany: Bundesministerium für Bildung und Forschung, Bundesinstitut für Berufsbildung.

Garzón, J., and Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. *Educational Research Review, 27*, 244-260.

Gavish, N., Guterriez, T., Webel, S., Rodriguez, J., Peveri, M., Bockholt, U., and Tecchia, F. (2015). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments, 23* (6), 778-798.

Green, M. (2017). *The future of technology and learning*. London, UK: Chartered Institute for Personnel and Development.

Hamilton, E., Rosenberg, J., and Akcaoglu, M. (2016). The Substitution Augmentation Modification Redefinition (SAMR) model: a critical review and suggestions for its use. *Tech Trends, 60* (5), 433-441.

Hippach-Schneider, U. and Huismann, A. (2016). *Vocational education and training in Europe – Germany*. Thessaloniki, Greece: Cedefop.

Hofmann, J. (2018). ARBT: augmented reality based trainings for vocational trainers in the field of chemistry. In R. Dachselt and G. Weber (Eds.), *Mensch und Computer 2018 - Workshopband* (pp. 393-400). Bonn, Germany: Gesellschaft fur Informatik.

Johnson, L., Witchey, H., Smith, R., Levine, A., and Haywood, K. (2010). *The Horizon Report: 2010 Museum Edition*. Austin, TX: Marcus Institute for Digital Education in the Arts.

Kaul, C., and Smith, J. (2018). *Evaluating the potential for virtual reality, augmented reality and gamification in rail industry safety critical training*. London, UK: Rail Safety and Standards Board.

Lave, J. (1988). *The culture of acquisition and the practice of understanding*. Palo Alto, CA: Institute of Research on Learning.

Lave, J., and Wenger, E. (1991). *Situated learning: legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lee, K. (2012). Augmented reality in education and training. *TechTrends, 56* (2), 13-21.

Miller, D., and Dousay, T. (2015). Implementing augmented reality in the classroom. *Issues and Trends in Educational Technology, 3* (2), 1-11.

Moodie, G. (2002). Identifying vocational education and training. *Journal of Vocational Education and Training, 54* (2), 249-266.

Nawaz, M., Kundu, S., and Sattar, F. (2017). Augmented reality sandbox and constructivist approach for geoscience teaching and learning. *International Journal of Educational and Pedagogical Sciences, 11* (6), 1603-1606.

Nuanmeesri, S. (2018). The augmented reality for teaching Thai students about the human heart. *International Journal of Emerging Technologies in Learning, 13* (6), 203-213.

Omar, M., Ali, D., Mokhtar, M., Zaid, N., Jambari, H. and Ibrahim, N. (2019). Effects of Mobile Augmented Reality (MAR) towards students' visualisation skills when learning orthographic projection. *International Journal of Emerging Technologies in Learning, 14* (20), 106-119.

Osmers, N., Blunk, O., and Prilla, M. (2019). *Augmented und Virtual Reality zur Unterstützung von betrieblicher Aus- und Weiterbildung in deutschsprachigen Unternehmen.* Clausthal-Zellerfeld, Germany: Technische Universität Clausthal. Retrieved from http://www.in.tu-clausthal.de/fileadmin/homes/HCIS/Documents/Abschlussreport_Interviewstudie.pdf, August 2019.

Ozdamli, F., and Hursen, C. (2017). An emerging technology: augmented reality to promote learning. *International Journal of Emerging Technologies in Learning, 12* (11), 212-137.

Ozdemir, M., Sahin, C., Arcagok, S. and Demir, M. K. (2018). The effect of augmented reality applications in the learning process: a meta-analysis study. *Eurasian Journal of Educational Research 74*, 165-186.

Paulk, M., Curtis, B., Chrissis, M. and Weber, C. (1993). *Capability Maturity Model for Software, Version 1.1*. Pittsburgh, PA: Carnegie Mellon University Software Engineering Institute.

Porter, N., Cota, A., Gifford, T., and Lam, W. (2006). Virtual reality welder training. *Journal of Ship Production, 22* (3), 126-138.

Richey, S. (2018). Utilizing presence in augmented reality applications to improve learning outcomes. *Performance Improvement 57* (4), 10-19.

Rios, H., Hincapie, M., Caponio, A., Mercado, E., and Mendivil, E. (2011). Augmented reality: an advantageous option for complex training and maintenance operations in aeronautic related processes. In R. Shumaker (Ed.), *Virtual and Mixed Reality: Part 1* (pp. 87-96). Berlin, Germany: Springer.

Schön, D. (1987). *Educating the reflective practitioner.* San Francisco: Jossey-Bass.

Sirakaya, M. and Kilic Cakmak, E. (2018). The effect of augmented reality use on achievement, misconception and course engagement. *Contemporary Education Technology, 9* (3), 297-314.

Stanton, G., Morris, A. and Norrington, J. (2015). What goes on in colleges? Curriculum and qualifications. In A. Hodgson (Ed.), *The coming of age for FE?* (pp. 68-88). London, UK: Institute of Education Press.

Wang, X., Ong, S. and Nee, A. 2016. A comprehensive survey of augmented reality assembly research. *Advances in Manufacturing 4* (1), 1-22.

Wellington, J. (1993). *The work-related curriculum*. London: Kogan Page.