A systematic review of digital innovations in technology-enhanced learning designs in higher education

Derek L. Choi-Lundberg
University of Tasmania, Australia

Kerryn Butler-Henderson
RMIT University and University of Tasmania, Australia

Kristyn Harman, Joseph Crawford
University of Tasmania, Australia

In the years prior to the COVID-19 pandemic, there was considerable innovation in designing and implementing teaching and learning with technology in fully online, face-to-face and blended modes. To provide an overview of technology-enhanced learning in higher education, we conducted a systematic literature review following PRISMA guidelines of digital innovations in learning designs between 2014 and 2019, prior to emergency remote teaching responses to the COVID-19 pandemic. From 130 publications, we identified eight overlapping categories of digital technologies being deployed across higher education fields: simulation and augmented or virtual reality; Web 2.0; learning management systems; mobile learning; gamification and serious games; various technologies in classrooms; massive open online courses; and other software, websites, applications and cloud computing. We use these publications, supplemented with findings from selected meta-analyses and systematic reviews of specific technologies, as examples to guide educators designing technology-enhanced learning activities in changing circumstances that may require blended or fully online delivery. As the 130 publications had mixed perceived quality, levels of evidence and details of learning designs and evaluation presented, we suggest educators share their innovations following reporting guidelines relevant to their research methodologies, enabling others to consider transferability to other contexts and to build on their work.

Implications for practice or policy:

- Leaders and administrators should support staff development of technological pedagogical content knowledge and teaching as design for student learning.
- Educators and instructional designers, in designing learning experiences, should consider adult learning theories, inclusive practices and digital equity and leverage multiple technologies to facilitate students learning their curricula.
- In educational research or scholarship of teaching and learning, researchers should provide sufficient detail to enable readers to assess transferability to their own contexts.

Keywords: cooperative and collaborative learning, learning communities, online learning, blended learning, technology-enhanced learning, teaching and learning strategies, systematic literature review

Introduction

Since the final decades of the 20th century, higher education (HE) academics, instructional designers and educational technologists have been innovating with technology-supported learning designs, with development and diffusion of innovation growing in pace and scale in the 21st century (Shen & Ho, 2020; Zawacki-Richter & Latchem, 2018). Over 4 decades to 2016, there has been a shift from computer-assisted learning (CAL) for individual instruction in classrooms to using networked computers and hand-held devices for communication and collaborative learning in face-to-face, online and blended learning environments (Zawacki-Richter & Latchem, 2018). Developments over the last 1 or 2 decades include audience-response systems in classrooms (Castillo-Manzano et al., 2016), augmented reality (AR, Garzón & Acevedo, 2019), virtual reality (VR, Radianti et al., 2020), mobile learning (m-learning, Sung et al., 2016), social network sites (Rodríguez-Hoyos et al., 2015) and massive open online courses (MOOCs, Lee et al., 2019). The COVID-19 pandemic has highlighted the importance of the HE sector being able to respond to students' needs using technology to support emergency remote teaching during unpredictable lockdowns (Hodges et al., 2020), in which HE staff worked from home and students studied online through learning management systems (LMSs) using synchronous and asynchronous online communication tools (Crawford et al., 2020). Skilful use of these tools is also essential for ongoing online programs (Saikat et al., 2021) and in the return to blended or hybrid learning environments (Thompson et al., 2021).

This article presents the results of a systematic review of pre-pandemic (2014–2019) literature on digital innovation in learning and teaching design across all broad fields of HE. This extends related work examining technology use in particular fields of education, such as health professional education (Grimwood & Snell, 2020) and anatomy education (Clunie et al., 2017), and provides additional years of publications not included in broad reviews of technology-enhanced learning (TEL) using a critical lens from 2005 to 2010 (Kirkwood & Price, 2014), bibliometric analysis from 1990 to July 2018 (Shen & Ho, 2020) or content analysis of titles and abstracts from one journal from 1976 to 2016 (Zawacki-Richter & Latchem, 2018), while avoiding emergency remote teaching responses to the pandemic addressed by other reviews (Crawford et al., 2020; Saikat et al., 2021). This article provides a broader overview than systematic reviews and meta-analyses of specific platforms or technologies, such as MOOCs (Davis et al., 2018) and mobile devices (Sung et al., 2016), or specific learning designs including flipped classroom (Hew et al., 2021).

Thus, the research question of this article was: What were digital innovations in HE, and how were they used in TEL designs, as reported in peer-reviewed publications from 2014 to 2019? To describe the characteristics of publications included in this review, the research sub-questions were as follows:

(1) In which countries were the innovations implemented?
(2) In which fields of education were the innovations implemented?
(3) What types of research methodologies were used?
(4) What levels of evidence were reported?
(5) What evaluative information was reported?

The value in addressing these questions is to provide a broad overview and systematic organization of empirical evidence available regarding digital innovation prior to the pandemic in 2020, enabling educators to explore technologies and learning designs that may be relevant to their contexts, and researchers and administrators to compare and contrast these findings to practices emerging during the pandemic (e.g., Butler-Henderson et al., 2021) that exacerbated pre-existing inequities (Willems et al., 2019), thus providing a baseline for future research and guidance to improve the reporting of evidence and evaluation in future studies.

We begin with a presentation of the theoretical frameworks for the study, followed by the methods of the systematic review. We then present a summary of characteristics of publications included in this review, the digital innovations and TEL designs they reported by technology categories, discussing these in the context of meta-analyses and other systematic reviews of specific technologies, concluding with implications for teaching practice and reporting future findings.

Theoretical background

We draw on four theoretical frames to guide the sample and analysis of manuscripts: digital innovation, teaching as design for student learning, Kirkpatrick's (1959) levels of evidence as adapted for HE contexts (Praslova, 2010) and Cook and Ellaway's (2015) TEL evaluation framework.

Digital innovation

The term *innovation* is frequently used loosely across industries, and therefore it was important to have a guiding definition to provide boundaries for the scope of this review. Relevant definitions include "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers, 2003, as cited in Kim & Jang, 2014, p. 206); and an "idea or item which is novel to a particular individual or group, and […] the change which results from the adoption of the object or idea" (Evans & Leppmann, 1970, as cited in Donnelly, 2019, p. 305). In the present review, a digital innovation in learning design is a technology that was introduced or used in a novel way by HE staff in their own learning and teaching practice, then evaluated and reported through publication.

Teaching as design for student learning

Developing teaching and learning activities incorporating technology is a design activity. Phases of teaching include planning, interaction (teaching), reflection and evaluation, with design occurring across this lifecycle (Goodyear, 2015). Designing for learning "rarely involves the creation of brand-new things – more often, it involves selections of existing things and their configuration into new assemblages" (Goodyear, 2015, p. 32). Teachers set curriculum and intended learning outcomes, design learning activities and assessment tasks, select resources including technologies, respond to feedback, seek to continually improve and adopt and sustain practices and technologies, within the constraints of disciplinary norms and university and accreditation requirements (Bennett et al., 2018). Such design activity requires technological pedagogical content knowledge, not only knowledge of technology, pedagogy and the content to be taught but also the two- and three-way intersections of these knowledge domains (Mishra & Koehler, 2006), or more simply, integrated knowledge of how to use technology to help students achieve specific learning goals (Saubern et al., 2020). Teachers' learning designs may be documented and shared for others to adapt to their context (Bennett et al., 2018), including through educational research or scholarship of teaching and learning publications (Boshier, 2009).

Levels of evidence

The Kirkpatrick levels of evidence (1959, as cited in Praslova, 2010) were devised for businesses to evaluate training programs and have been modified for many contexts including HE. The four levels and examples are:

1. Reaction. Satisfaction, enjoyment, usefulness and useability of technology, self-perception of learning.
2. Learning. Measured learning (knowledge, skills or attitudes), such as through pre- and post-implementation tests, possibly compared to a control group.
3. Behaviour. Transfer of learning to other contexts, such as other courses, work-integrated learning (WIL), internships or employment.
4. Results. System-level impacts on institutions, communities or society (Praslova, 2010).

Levels 1 and 2 happen within the course, whereas Levels 3 and 4 typically occur in subsequent courses or beyond formal learning (Praslova, 2010). We added Level 0: Engagement, for learning analytics data, although the new world Kirkpatrick model and a few other adaptations include engagement in Level 1 (Allen et al., 2022). Conceptually, students must engage with learning resources and activities to have opinions of (Level 1), learn from (Level 2) and apply (Level 3) them. Furthermore, considering actual usage (Level 0) separate to reactions (Level 1) conceptually links to adoption of technological innovation models including the technology acceptance model or unified theory of acceptance and use of technology. Engagement data is actual usage, which is influenced by perceived usefulness, usability, social influences from teachers or peers, and facilitating conditions (Venkatesh, 2003).

TEL evaluation framework

The Cook and Ellaway (2015) framework for evaluating TEL consists of seven data collection and reporting categories: (a) needs analysis and environmental scan; (b) goals, processes, decisions and product; (c) testing of usability; (d) implementation; (e) participant opinions (Kirkpatrick Level 1); (f) learning outcomes (Kirkpatrick Levels 2, 3 and/or 4); and (g) cost and sustainability. This framework is broader than Kirkpatrick's, which largely focuses on outcomes. Together, these enable a more comprehensive assessment of the use of the technology in the learning design.

Methods

Search strategy

The study adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Moher et al., 2009) for publication selection. The databases EBSCO, Informit, Ovid, ProQuest, Scopus and Web of Science were searched in September 2019 and again in July 2020 to capture the rest of 2019, with a resultant combined date range of 1/1/2014 to 31/12/2019, using the following keyword string: [Digital OR electronic OR elearning OR e-learning OR online OR blended OR environment OR ecology OR mobile OR virtual OR "mixed reality" OR "augmented reality"] AND [Design OR development]) AND [Teaching OR learning OR pedagogy OR curriculum]) AND ["Higher education" OR tertiary OR university OR college]) AND [Innovate OR innovation OR innovating]. The search string for each database is presented in Appendix A.

The search string was developed through discussion amongst the authors and trialled, including reviewing keywords from some publications identified with initial search strings. A few specific terms (e.g., *mixed reality* or *augmented reality*) were added to capture studies where authors may not have also used more generic terms such as *electronic* or *mobile*. All results (*n* = 7,064) were exported into an EndNote library, duplicates (*n* = 1,753) eliminated and records for screening (*n* = 5,311) transferred into Covidence, systematic review software that applies the PRISMA method (Figure 1).

Selection procedure

Inclusion criteria for the systematic review were peer-reviewed publications including journal articles, conference papers or book chapters, available freely online or through institutional subscriptions in full-text English, which reported empirical research or a review thereof in an HE context of one or more technologies used in learning designs. Exclusion criteria were opinion pieces, commentaries, editorials, conceptual innovations or descriptions of innovations without any empirical evidence. Titles and abstracts were single-screened (*n* = 5,311) (Figure 1), with each of us screening between 617 and 2,368 publications. Full-texts were single-reviewed for eligibility (*n* = 557), with each of us reviewing between 92 and 202 publications. At each stage, if the screener or reviewer was uncertain if criteria were met, it was progressed to the next phase. A second review of included full-texts took place during data extraction (*n* = 130), with each of us writing a brief narrative summary and extracting information from between 23 and 39 of the included publications, as described below. Differences of opinion on whether to include or exclude were resolved through discussion or a third reviewer, who was another of us.

Data extraction and quality assessment

One of us extracted levels of evidence and TEL evaluation framework information (Cook & Ellaway, 2015) for all included publications. Data extracted from each publication in the final sample consisted of:

- citation, reference and publication type
- country where teaching took place, or if not specified, country of the first author's institution, and later categorised by geographic region as per the United Nations Statistics Division (2021), for Research sub-question 1
- disciplines, later categorised by two-digit level field of education codes (UNESCO Institute for Statistics, 2015), for Research sub-question 2
- type of research methodologies and quality rating as per the Mixed Methods Appraisal Tool (MMAT, Hong et al., 2018) or the Quality Assessment Tool for Theory and Literature (QATTL, Crawford et al., 2023), for Research sub-question 3

- levels of evidence using a modified Kirkpatrick model for HE (Praslova, 2010), for Research sub-question 4
- evaluation information about context and implementation of the digital innovation and learning design using a TEL evaluation framework (Cook & Ellaway, 2015), for overarching research question and Research sub-question 5
- digital innovations and technologies (later thematically grouped into categories) and learning designs used, for overarching research question
- format of course (face-to-face, blended, and/or online)
- number and type of participants (students, staff and/or others).

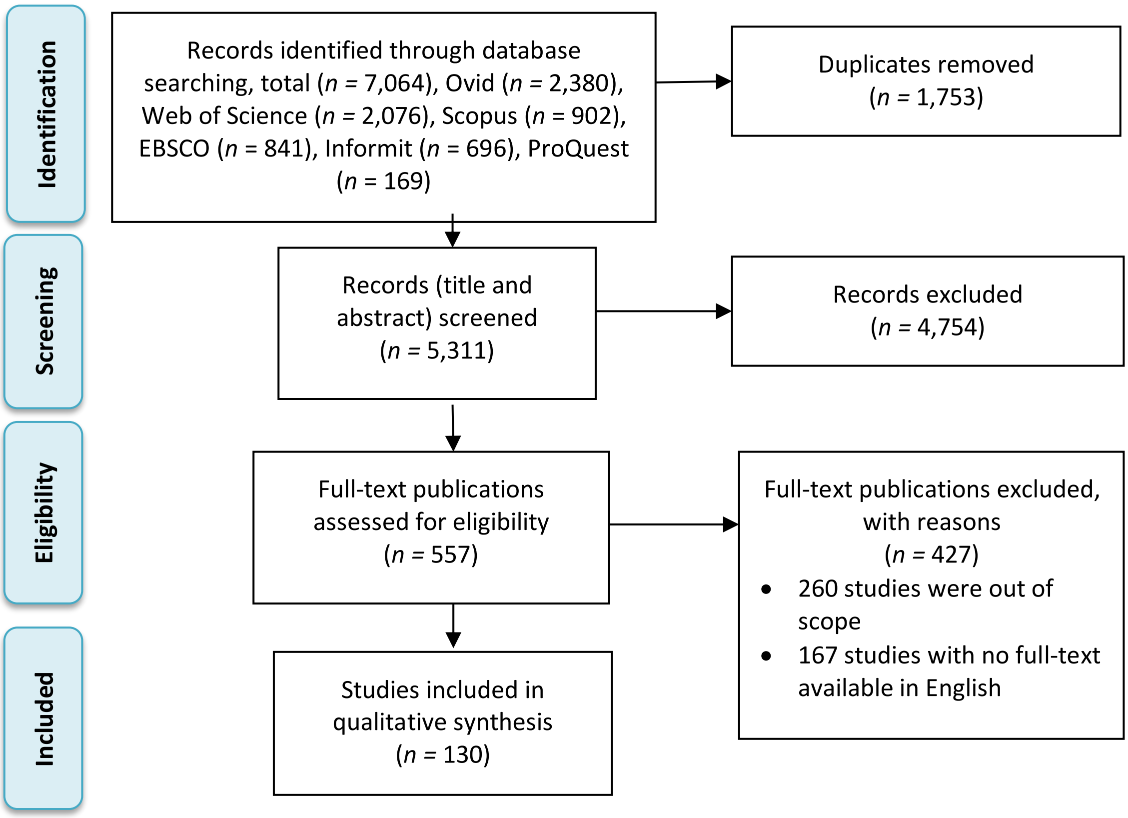

Figure 1. PRISMA diagram of literature search and systematic review processes (after Moher et al., 2009)

MMAT facilitates quality assessment of empirical studies with (1) qualitative methods; quantitative methods including (2) randomised controlled trials, (3) non-randomised comparative and (4) descriptive studies; and (5) mixed methods. There are five questions for each of these five categories which are answered *yes*/*no*; qualitative or quantitative publications with 0 or 1 *yes* answers (0 or 20% of possible *yes* answers) were rated low, 2 or 3 (40% or 60%) medium and 4 or 5 (80% or 100%) high, to create three categories with two scores each. For mixed methods studies, the qualitative, relevant quantitative and mixed methods questions are used, for a total of 15 questions; publications with 0 to 4 *yes* answers (0 to 27% of possible *yes* answers) were rated low, 5 to 9 (33% to 60%) medium and 10 to 15 (67% to 100%) high, creating three categories with five or six scores each. As MMAT is not appropriate for non-empirical publications, QATTL was used to assess the quality of non-empirical publications (reviews) included in this study. There are 15 criteria, each scored 0, 1 or 2 for the criterion being not met, partially met or fully met respectively; 0%–32% was rated low, 33%–66% medium and 67%–100% high (the above-defined MMAT low, medium and high category percentages align with these QATTL percentages). One of us rated all included publications using MMAT or QATTL and another of us or a research assistant completed a second set of ratings, compared with a correlation coefficient (Pearson's r). A Mann-Whitney U test (a non-parametric version of an independent samples t test) was used to compare MMAT quality ratings of included conference papers and journal articles, as the Shapiro-Wilk test indicated data were not normally distributed. IBM SPSS Statistics version 28 was used for statistical analyses.

Analysis of manuscripts

Digital innovations and technologies described in each publication and identified during extraction were iteratively grouped into categories discussed amongst us. A final set of eight overlapping categories was agreed, and one of us subsequently reviewed each publication and identified which category or categories were central. Extracted information on digital innovations and learning designs and their contexts were repeatedly read and used to write narrative summaries of innovations in each of these eight categories. Exemplars were chosen from included publications, with greater representation from publications rated high or medium quality. All publications are listed in Appendix B together with selected summary information.

Results and discussion

The study selection PRISMA method (Figure 1) resulted in the inclusion of 130 publications, consisting of two book chapters, 26 conference papers and 102 journal articles, collectively from 39 countries or areas (Research sub-question 1, Table 1) and all broad fields of education (Research sub-question 2, Table 2). Various research methodologies were used (Research sub-question 3, Table 3).

At least one Kirkpatrick level of evidence was presented in all but six publications (Research sub-question 4, Table 4), with many including two or three levels of evidence; and across the publications wide varieties of evidence were presented in Levels 0, 1 and 2 (Appendices B and C). Information related to TEL evaluation using Cook and Ellaway's (2015) framework was presented in all publications (Research sub-question 5, Table 5) and ranged from one to all seven categories per publication. Most publications included needs analysis, processes, participant experiences and implementation, but the amount of detail was variable across publications with many providing only superficial information (Appendices B and C). The delivery mode of courses was blended (n = 62 publications), online (n = 38), face-to-face (n = 28) or not described (n = 10); the total exceeds 130 due to some publications describing more than one delivery mode (e.g., a course available in blended or fully online modes) or reviews describing more than one delivery mode (Appendix B). Nearly half of the included publications were rated low quality using MMAT (Appendix C).

Using innovation-related search terms resulted in only a small percentage of publications on TEL in HE being included, but eliminating these terms resulted in over 70,000 publications, too many for manual screening. Therefore, to put the included publications in a broader context, targeted database and hand searches were conducted for systematic reviews and meta-analyses of the digital innovation categories from selected top-ranked journals in Scimago Journal & Country Rank education subject category (*Review of Educational Research*, *Computers & Education*, *Educational Researcher* and *Educational Research Review)* and *Australasian Journal of Educational Technology*. The following sections provide a narrative summary of 65 included publications (85% of high, 67% of medium and 26% of low-quality publications) selected to illustrate the types of digital innovations, learning designs and findings reported, supplemented with chosen meta-analyses and other systematic reviews of specific technologies.

To address the overarching research question, digital innovations and technologies implemented in learning designs in included studies were classified into eight categories of technology: simulation, AR and VR (n = 46); web 2.0 including blogs, microblogs, social media and wikis (n = 39); LMS (n = 22); m-learning (n = 22); gamification and serious games (n = 18); technology in classrooms (n = 16); MOOCs (n=10); and other software, websites, applications and cloud computing (n = 35). Many publications reported on technologies from two (n = 43) or more (n = 15) categories, and some technologies span categories, such as mobile AR; hence, the total exceeds the number of included publications. Summaries and examples of their use in learning designs follows.

Simulation, AR and VR

Simulation, AR and VR provide innovative technological approaches to learning and teaching. These technologies overlap: AR combines physical reality and VR, which is a computer-generated simulation of a three-dimensional environment. These technologies improve student confidence (Stewart-Lord, 2016) and the attainment of learning outcomes (Deng et al., 2018; Gamo, 2019) when implemented with various pedagogies including collaborative learning designs (Phon et al., 2014). A meta-analysis found large learning gains from AR for undergraduates (d = 0.83) across 18 publications (Garzón & Acevedo, 2019). Part of the appeal of AR, VR and simulations is their capacity to facilitate authentic learning through providing models of environments in which students' skills will ultimately be applied (Matthew & Butler, 2017). For example, virtual WIL for construction management students studying online was enabled by 360-degree images of construction sites over time supplemented with additional photos, video interviews with experts and building plans presented via guided online learning activities (Quinn et al., 2019).

Table 1
Geographic regions and countries or areas in which studies were conducted

Geographic region	Country or area	No. (percentage) of publications (region)	No. of publications (country or area)
Europe		42 (32%)	
	Spain		15
	United Kingdom		12
	Portugal		5
	Ireland		3
	France, Italy		2 each
	Belgium, Czech Republic, Finland, Germany, Hungary, Netherlands, Russian Federation, Serbia, Ukraine		1 each
Americas		34 (26%)	
	United States of America		23
	Brazil, Canada, Mexico		3 each
	Chile, Ecuador, Trinidad and Tobago		1 each
Oceania		32 (25%)	
	Australia		32
	New Zealand		1
Asia		27 (21%)	
	China		5
	China – Hong Kong Special Administrative Region		4
	Malaysia, Thailand, Turkey		3 each
	Cyprus, Kazakhstan		2 each
	India, Iran, South Korea, Qatar, State of Palestine		1 each
Africa		5 (4%)	
	South Africa		3
	Ethiopia, Morocco		1 each

Note. Totals exceed the number of publications (130) because teaching occurred in two or more countries or areas in many publications. Geographic regions, countries and areas are as per the United Nations Statistics Division (2021).

Table 2
Fields of education at two-digit code level (UNESCO Institute for Statistics, 2015) of included studies

Field of education	No. (percentage) of publications
Education (01)	32 (25%)
Health and welfare (09)	31 (24%)
Engineering, manufacturing and construction (07)	27 (21%)
Arts and humanities (02)	16 (12%)
Natural sciences, mathematics and statistics (05)	15 (12%)
Business, administration and law (04)	14 (11%)
Information and communication technologies (06)	9 (7%)
Social sciences, journalism and information (03)	7 (5%)
Generic programs and qualifications (00)	5 (4%)
Services (10)	5 (4%)
None specified	3 (2%)
Agricultural, forestry, fisheries and veterinary (08)	2 (2%)

Note. Totals exceed the number of publications (130) because many included two or more fields of education.

Table 3
Research methods as per the Mixed Methods Appraisal Tool (MMAT, Hong et al., 2018)

Study category	Category of quantitative study or quantitative component of mixed methods studies	No. (percentage) of publications	No. (percentage) of publications
Mixed methods		58 (45%)	
	Descriptive		46 (35%)
	Non-randomised comparative		10 (8%)
	Randomised controlled trial		2 (2%)
Quantitative		45 (35%)	
	Descriptive		28 (22%)
	Non-randomised comparative		15 (12%)
	Randomised controlled trial		2 (2%)
Qualitative		22 (17%)	
Review		5 (4%)	

Table 4
Kirkpatrick levels of evidence of included studies

Level	No. (percentage) of publications
Level 0 (Engagement)	27 (21%)
Level 1 (Reaction)	113 (87%)
Level 2 (Measured learning outcomes)	44 (34%)
Level 3 (Behaviour)	2 (2%)
Level 4 (Results)	5 (4%)

Note. Totals exceed the number of publications (130) because many publications included two or more levels of evidence.

Simulations, VR and AR allow science, technology, engineering and mathematics (STEM) students to visualise abstract scientific concepts, engage in experiential learning, apply theoretical knowledge and investigate phenomena not possible in typical university teaching laboratories (Arici et al., 2019). Virtual and remote laboratories are typically less expensive, more accessible and safer than conventional physical laboratories (Heradio et al., 2016). For example, engineering students learned to operate complex robotic equipment in a simulated environment without damaging expensive machinery (Li et al., 2018). Computer science students gained experience in a cloud-based virtual cybersecurity laboratory platform with virtual machines and network, which supported self-paced learning and personalised adaptive instruction based on data mining of student learning behaviour in the system analysed with machine learning (Deng et al., 2018).

Table 5
Cook and Ellaway (2015) evaluation framework information presented in included studies

Evaluation component	No. (percentage) of publications
Needs analysis	123 (95%)
Processes	114 (88%)
Usability testing	24 (18%)
Implementation	115 (88%)
Participant experiences (Kirkpatrick Level 1)	113 (87%)
Learning outcomes (Kirkpatrick Levels 2, 3 and/or 4)	50 (38%)
Cost and/or sustainability	46 (35%)

Note. Totals exceed the number of publications (130) because many publications included two or more evaluation components.

Simulation allows health students to interact with virtual patients and colleagues, developing clinical reasoning and decision-making skills in safe environments ranging from low to high fidelity. Nursing students engaged in case-based learning randomised to a virtual simulator environment (virtual patients with dynamic physiological data) retained more knowledge and had higher satisfaction than a control group randomised to a physical simulator (Padilha et al., 2019). Nursing students' confidence improved through using simulated electronic health records and an online drug reference database during face-to-face case-based learning, which provided safe learning opportunities prior to clinical experiences, or if access to actual patients' electronic health records is not allowed (Vana & Silva, 2014).

Beyond STEM and health disciplines, collaborating and socialising in VR settings using avatars facilitated greater fluidity in roles, collapsed geographical distance, generated a sense of co-presence and belonging to the virtual campus and learning community and supported peer-to-peer learning (Bower et al., 2017; Gil Ortega & Falconer, 2015). The law subject of Trusts was enhanced with Mosswood Manor in the virtual world Second Life. Through participating in structured activities and assessment tasks built around life problems of the manor's virtual inhabitants, students appreciated the relevance and complexity of negotiations and trusts to law practice (Matthew & Butler, 2017).

Web 2.0

Implementation of Web 2.0 has continued from its inception in 1999 to support participation and social interaction (Rodríguez-Hoyos et al., 2015). Publications in the sample typically used one or more existing Web 2.0 technologies, particularly social media to support students with familiar platforms, often along with other technologies, to promote communication, teacher-to-student and peer-to-peer resource sharing, collaboration, peer feedback and inquiry. Platforms included Facebook (Salmon et al., 2015), podcasting (Kim & Jang, 2014), Twitter (Marin et al., 2014), WeChat (Dai et al., 2018), WhatsApp (Willemse et al., 2019), webcasting (Freguia, 2017), wikis (Guinau Sellés et al., 2017) and YouTube (Cobley & Steven, 2014). In contrast, McCarthy (2015) developed the Café, a custom learning environment within Facebook, to better leverage its capabilities. Blogging supported intercultural understanding (Bridges et al., 2014) and widening participation, with low-income students writing about their transition to university to create supportive networks and promote retention and success (Kreniske et al., 2019). Some authors applied theoretical or pedagogical lenses to blogging, such as reflexivity, communities of practice and inclusive practices in teacher education (Caldwell & Heaton, 2016); self-regulated learning including reflection on development of professional competencies and professional identity (Pinya & Rossello, 2016); or connectivism and professional learning networks (Graham & Fredenberg, 2015). While Web 2.0 technologies themselves are no longer innovative, it is their nuanced connectivity that creates opportunities for learning designs. Students can be empowered to select technological pathways to communicate, collaborate, and exchange feedback, supporting establishment of communities of practice and inquiry. Such flexibility and integration with other technologies such as LMSs (Ngai et al., 2019) create challenges for educators and scholars to demonstrate the efficacy of individual tools.

LMSs

First developed in the 1990s, digital learning environments or LMSs combine a variety of synchronous and asynchronous tools to support e-learning or m-learning in blended learning and fully online modes, including for communication, collaboration, content delivery, teaching and learning activities, assessment and feedback, with interoperability with other e-learning software to support teacher-centred and student-centred pedagogies (Weller, 2020; Zawacki-Richter & Latchem, 2018). There are many commercial and open-source LMSs, and some faculty develop their own LMS or add-ons, for example, to support students in navigating flipped classrooms with weekly visual and text guides to learning outcomes and tasks (Reidsema et al., 2014). Flipped classroom pedagogy relies on an LMS to deliver pre-class materials and learning activities, which may include recorded lectures, vodcasts, podcasts, annotated lecture slides, interactive online modules, readings, formative assessments with instant feedback and links to external resources (McLaughlin et al., 2016). Students engaged more before face-to-face classes when multimedia lectures (voice-over presentation slides) were the main resources compared to textbook chapters and journal articles (Freguia, 2017). An LMS enabled fully online media design courses that usually relied on face-to-face studio teaching: lecture content was delivered using short videos, the studio critique was replicated through discussion boards in which tutors and peers provided written formative feedback on work-in-progress design assignments created with Adobe Illustrator, and web conferencing enabled synchronous interaction (Fleischmann, 2019).

Theoretical frameworks such as the community of inquiry (Garrison et al., 2010) were used to design learning experiences (teaching presence) and communication opportunities to establish trust and shared purpose (social presence) within the LMS (Cooper & Scriven, 2017). Teachers can develop immediacy (psychological closeness) and the learning community through collaborative problem-based or project-based learning supported with discussion boards (Fahara & Castro, 2015), in which students explained concepts and case studies, shared knowledge and resources, sought help, gave feedback and monitored group effort (Ngai et al., 2019). An LMS and VoiceThread software enabled digital storytelling incorporating peer feedback to encourage reflection, critical thinking and empathy development (Price et al., 2015).

Staff can use an LMS to broaden participation in HE, supporting geographically dispersed students from non-traditional backgrounds through resource provision in multiple, accessible formats and student-centred collaborative learning designs to support the co-construction of knowledge and the sharing of experiences. Evening web conferences supported students to participate actively through polling, interacting socially, asking questions and sharing opinions, with frequent staff feedback (Andrew et al., 2015). Scaffolded academic and information literacy curricula were integrated with assessment tasks and embedded in the course LMS; learning analytics indicated high engagement, and teachers observed improvement in students' writing skills and grades (Nallaya et al., 2018).

M-learning

Small, portable, wireless devices such as smartphones and tablets, and their software and mobile apps, can enable flexible anytime anywhere learning for a variety of purposes including accessing and creating multimedia content; VR, AR and clicker capability; situated learning with geolocation context sensitivity; and collaborating and communicating with peers and teachers via Web 2.0 (Aguayo et al., 2017; Sung et al., 2019; Vazquez-Cano, 2014). Learners with English as an additional language were supported to develop their fluency in spoken English with Hit Counter and Ah-Counter mobile apps, using smartphones to record and evaluate their speech for rate, non-lexical fillers and interjections, enabling self-regulation of learning and peer and teacher feedback through weekly speaking journals (Cobley & Steven, 2014). Custom-designed mobile AR software overlaid 3D virtual models over real 2D projection drawings and enabled rotation and viewing of 3D virtual models from different angles to support skill development in interpreting and producing 2D projections (Cheng et al., 2018). Smartphones facilitate situated experiential learning: short mobile lectures provided guided tours to situate urban design theory in real urban environments; students recorded their reflections, which encouraged critical thinking (Lim et al., 2016). A systematic review across all levels of education reported m-learning studies are shifting from content delivery to supporting interaction but cautioned that m-learning may enhance or deter self-regulated learning (Palalas & Wark, 2020). A meta-analysis found mobile devices enhanced learning (*d* = 0.60 for 43 studies at college level), with higher effect sizes for inquiry-oriented learning (Sung et al., 2016).

M-learning can improve access to education in lower resource settings. The Hike Messenger app was used for m-learning while on WIL: teachers shared learning resources and links to reference materials and posed questions for students to answer, and students could ask questions (Patil et al., 2016). Inexpensive mobile instrumentation such as the Mobile Studio IOBoard or Digilent Analog Discovery enables students to conduct engineering laboratory experiments that previously required expensive equipment in face-to-face laboratories (Astatke et al., 2015). However, Kaliisa and Picard's (2019) critical review highlighted the need for African governments and HE institutions to address structural inequalities preventing many students from accessing m-learning.

Gamification and serious games

Gamification is the integration of game-like strategies into learning, such as points, badges or leader boards. In contrast, serious games are designed for the purpose of learning, incorporating realistic scenarios that prompt application of knowledge and critical evaluation. Both aim to motivate learning through psychology and engaging activities. de Oliveira Durso et al. (2019) used the Business Simulation Game for students working in small groups to make business decisions and analyse outcomes, similar to Hilliard's (2014) use of People Power for political decision-making in non-violent social conflict scenarios. Serious games can be integrated with other technologies and learning designs; for example, Edmonds and Smith (2017) used location-based m-learning games that integrated gamification, digital storytelling and location-based m-learning, which strengthened students' location awareness and provided environmental contexts to authentic learning experiences, improving engagement. Students subsequently designed and developed location-based m-learning games, activating their creativity and learning cooperatively with peers and from their environment. Borras-Gene et al. (2016) gamified a cooperative MOOC, combining a virtual learning community, social media elements and certificates and badges to incentivise learning. A meta-analysis demonstrated enhancement of learning across K-16 when games and gamification were compared to non-game learning environments (Clark et al., 2016).

Technology in classrooms

Some technologies are targeted for face-to-face classroom environments. Videoconferencing was used to conduct tutorials across three continents to develop intercultural communication skills through facilitated discussions, presentations and debates (Bell & Carr, 2014). Collaborative learning spaces enabled small groups to control large touchscreen computers to share electronic resources; alternatively, the lecturer could share content with all stations or share one station's content with others (Dobinson & Stokes-Thompson, 2015). Such spaces enabled students to explore digital histology slides in laboratories, in conjunction with instant response systems (Felszeghy et al., 2019). Clickers or instant response systems allow students to anonymously answer questions, provide opportunities to rehearse and retrieve information, stay engaged through gamification elements, provide instant feedback to students and teachers on the students' misconceptions and provide records of attendance and performance (Alaeddine et al., 2015; Cheung et al., 2018). Meta-analyses at tertiary level found clickers had small positive influences on learning (g = 0.22, Castillo-Manzano et al., 2016), cognitive outcomes (g = 0.05) and knowledge transfer (g = 0.11, Hunsu et al., 2016); both reported greater benefits in social and medical sciences. Learning designs used with clickers influence outcomes: another meta-analysis indicated greater learning for students explaining and justifying their answers to peers, compared to explanations from teachers (Chien et al., 2016).

Laboratories in which sensors, interfaces and computers are used to capture, process and analyse experimental data from equipment enable students to focus on interpreting rather than manually collecting data, and facilitate exploring relationships amongst variables through automatically generated graphs (Sari et al., 2019). Studios equipped with electronic boards and sensors (e.g., Raspberry Pi, Arduino) and additive (3D printing) and subtractive (laser-cutting) rapid-prototyping manufacturing devices enabled industrial design and electronics students to collaboratively develop tangible user interfaces through iterative prototyping with frequent feedback from industry partners and users via blogging (De Ville et al., 2016). Such design studios or maker spaces align with constructionism learning theory: learning through the process of making and developing students' innovation, creativity and entrepreneurialism in multidisciplinary contexts (Halverson & Sheridan, 2014).

Technology in classrooms can support widening participation in HE. For example, a digital literacy course within an enabling pathway used universal design for learning principles: provide multiple modes of representation in learning resources and opportunities for expression in assessment tasks (Stokes, 2017). Students pitched projects, received peer and lecturer feedback and created digital media using classroom production kits and multimedia tools (Stokes, 2017). First Nations people living in remote locations may face challenges relocating to university or accessing adequate technology and Internet or mobile coverage at home. Possible solutions include equipping community resource centres with computers, providing reliable Internet and culturally appropriate support for students' information and communication technology skills development (Wilks et al., 2017).

MOOCs

MOOCs are well documented in the literature (Liyanagunawardena et al., 2013) but are novel in some contexts. Several publications discussed expansions beyond traditional MOOCs, including integration of social media, collaboration and gamification, to respond to their weaknesses, including lack of authenticity and interaction, difficulty assuring achievement of learning outcomes and low retention. Social media (Twitter and Facebook) was used to support an education-based MOOC; however, while 14% of participants engaged with both platforms, citing benefits to networking and knowledge-sharing, 41% perceived social media in the MOOC as a "waste of time" and did not engage with either platform (Salmon et al., 2015, p. 7). Teixeira et al. (2019) designed for inclusion, individual responsibility, interpersonal relationships and innovation in their climate change iMOOC and focused on embedding social justice within a digital competency for educators sMOOC; both MOOCs incorporated pedagogies of connectivism, situated learning and socioconstructivism. Teixeira et al.'s iMOOC had strong early engagement but a continual decline after 1 month; high attrition remains an ongoing challenge for MOOCs. Davis et al. (2018) reviewed 126 studies on MOOCs, with cooperative, gamified and interactive learning environments identified as most successful.

A MOOC incorporating a machine learning tool to monitor participation and provide personalised learning support with innovation-based learning pedagogy through student-faculty collaborative projects on real-world problems holds the potential for improving engagement, collaboration, and higher-order learning outcomes; a similar discovery-based learning course produced outcomes including spin-off companies, patents, funded grants, and journal and conference publications (Swartz et al., 2019). Some MOOCs are targeted for academics: a connectivist MOOC engaged clinical educators in continuing professional development and generating open educational resources for medical education (Chan et al., 2015). Innovations for the next phase of MOOCs rest on seamless application of online collaborative pedagogies and integration of other technologies.

Other software, websites, applications and cloud computing

Software innovations are changing how learning and teaching is designed and delivered. The learning design process of academics was supported with the web platform Integrated Learning Design Environment, complemented by teacher professional development workshops and follow-up support, enabling successful design and implementation of collaborative learning experiences (Asensio-Perez et al., 2017). Adobe Captivate was used to develop video diaries, online virtual cases and interactive materials in mental health (Hassoulas et al., 2017). Self-paced multimedia problem-based learning materials were created with Scenario Based Learning Interactive software (Blackburn, 2015). Mechanistic case diagrams supported teachers to author web-based case studies with concept mapping for students to link basic and clinical sciences knowledge via problem-based learning (Ferguson et al., 2018).

A wide variety of existing general, specialist or educational software, websites and apps, and custom-developed bespoke programs were reported in the included publications. For example, the Google app suite was used to support learning English as an additional language through literature circle discussions and group work on shared files (Intriago et al., 2016) or for teamwork on case studies (Holmes et al., 2015). Google Docs files were used in conjunction with Web 2.0 tools and web conferencing for cross-cultural communication, collaboration and presentation of project-based learning (Guariento et al., 2016). Student teachers learned infographic design software, promoting analysis, synthesis and creativity in conveying complex scientific concepts visually and concisely (Fadzil, 2018). Many studies incorporated several different tools; for example, James et al. (2016) utilised Moxtra, Padlet, Weebly and NVivo. Custom-designed innovations included Flexible Electronic Report Writing Tool to support writing in the discipline (Drury & Muir, 2014). Staff have vast software and app choices to incorporate into learning, potentially resulting in multiple platforms being used in different courses, requiring learners to learn many technologies that may not be fit for purpose, and placing them at security risk if technologies are not integrated into the institution's credentialling system. Conversely, specialist software allows learners to experience key industry software to develop work-ready capabilities.

Implications for practice

Incorporating technology in quality learning experiences is increasingly expected by HE students for whom technology is omnipresent, and this may improve retention as students decide whether they are receiving value for time and money (Quinn et al., 2019). Yet, despite the ubiquity of technology, Smith et al. (2020) cautioned against stereotyping students as digital natives, emphasising the importance of supporting students to enhance their digital literacies, which include communicating appropriately in learning communities and accessing, curating, creating and sharing digital content ethically (Willems et al., 2019). It is not technologies alone but their orchestration with suitable learning designs in supportive learning environments that lead to learning. Learning designs should incorporate digital equity considerations such as availability and accessibility of technologies considering socio-economic background and inclusive practices (Willems et al., 2019); supporting students' psychological needs of autonomy, competence and relatedness (Ge et al., 2019); training needs of students (Holmes et al., 2015); and likeliness of use of technologies (Venkatesh, 2003). Professional development for staff should include not just learning technologies themselves but how to incorporate technologies to support student learning in their subjects and courses (Mishra & Koehler, 2006; Saubern et al., 2020). During the lockdowns caused by the COVID-19 pandemic, a rapid shift to fully online delivery of learning experiences was required (Crawford et al., 2020). Ongoing uncertainty and student expectations for flexibility require ongoing blended and fully online courses implementing multiple technologies integrated in suitable learning designs, which HE staff could develop or adapt based on the findings of the present review and the cited publications.

Although not always specified, most included publications utilised blended learning, incorporating face-to-face and online learning activities (Appendix B). A systematic review highlighted four challenges in designing blended learning experiences: (a) promoting flexibility; (b) interactions; (c) facilitating self-regulated learning; and (d) attending to affective climate and emotional engagement (Boelens et al., 2017). Many publications highlighted good practice to meet these challenges: (a) Various technologies, particularly m-learning, promote learner flexibility in place, time and pathway of learning (Astatke et al., 2015). (b) To build social connections and learning communities, technology was leveraged to facilitate connections, communication and collaboration amongst staff and students (Caldwell & Heaton, 2016; Guinau Sellés et al., 2017). (c) Self-regulated learning was promoted by familiarising students with technologies, clearly communicating expectations, facilitating peer interaction and feedback (Fleischmann, 2019; McCarthy, 2015), and encouraging reflection (Pinya & Rossello, 2016). (d) Climate, emotional engagement and social presence can be promoted through group learning activities with technologies to facilitate collaboration and communication (Fahara & Castro, 2015). Learning designs and technologies can help widen participation through supporting disadvantaged groups (Kreniske et al., 2019, Wilks et al., 2017) and promoting accessibility of learning resources and activities (Stokes, 2017), and provide global perspectives and connections to promote intercultural understanding (Guariento et al., 2016).

Limitations and suggestions for future reporting

This systematic review was limited by a single screening by the four of us at title and abstract phase (*n* = 5,311) and full-text phase (*n* = 557) due to the large number of publications. However, if there was uncertainty if inclusion criteria were met, items were progressed to the next phase, and a second review of full texts occurred at extraction phase. Single instead of double screening undoubtedly resulted in fewer publications being included in the review. Furthermore, publications for which full texts were not available in English freely online or through our institution's subscriptions were excluded; nevertheless, publications were included from all geographic regions (Table 1). Additionally, only peer reviewed publications were included, while emerging innovations described in reports, dissertations and white papers were excluded. Inclusion of search terms relating to innovation meant only a fraction of all reports on TEL was screened; adding meta-analyses and other systematic reviews on individual technologies from selected top journals provided broader coverage and additional resources for readers.

Of the 130 publications included in this systematic review, only seven reported Kirkpatrick Levels 3 or 4, evidence of transfer of learning to employment or impacts on communities or external organisations. Approximately one-third presented Kirkpatrick Level 2, measured evidence of learning outcomes; four studies were randomised controlled trials, and about 20% were non-randomised comparative studies. As technologies and associated learning designs mature past innovation stage, rigorous quantitative research designs can provide stronger evidence of impact on students' learning. Furthermore, studies across qualitative and mixed methods can provide a rich picture of TEL designs and how they promote learning, particularly when adequate detail of the context and rationale for incorporating technologies is made explicit (Kirkwood & Price, 2014), which can be guided by evaluation frameworks such as that of Cook and Ellaway (2015). Using this framework in the present review revealed that publications presented some relevant information but often lacked detail. Ratings using MMAT or QATTL revealed almost half of the studies were low quality. Authors can improve the quality of their studies and reporting through following published guidelines for designing and reporting studies, for example, "Checklist for the Rigor of Education-Experiment Designs" and others cited by its authors (Sung et al., 2019), Journal Article Reporting Standards for Quantitative Research in Psychology (Appelbaum et al., 2018) and for mixed methods and qualitative research (Levitt et al., 2018; O'Brien et al., 2014). Providing details on learning contexts also assists future scholars conducting meta-analyses, enabling extraction of information related to moderator variables (Hew et al., 2021).

Conclusion

This systematic review of 130 publications published from 2014 to 2019, supplemented with meta-analyses and other systematic reviews, identified a wide range of technologies and learning designs implemented to facilitate learning in fully online, blended or face-to-face modes and support student success across fields of education globally. These technologies are not new; most were evident in a latent semantic analysis of TEL in Web of Science over 1990–2018 (Shen & Ho, 2020), although mobile AR and VR are emerging areas with potential to shift from teacher- to learner-generated content and provide authentic learning experiences (Aguayo et al., 2017). In innovating with technology, staff should consider adult learning theories, teaching as design for learning, how technologies can enhance their diverse students' learning and explain to students why educational technologies are used and how best to utilise them for collaborative learning (Bedenlier et al, 2020).

This review provides a foundation for educators seeking to understand the digital innovation climate. Many technologies are being adapted for delivery during the pandemic, and some may become obsolete in future years. This review recommends educators consider how technologies can be implemented with learning designs in their specific curricular contexts to improve student learning and follow evaluation and reporting guidelines to share their practice.

Author contributions

Derek L. Choi-Lundberg: Data curation, Formal analysis, Investigation, Project administration, Validation, Writing – original draft, Writing – review and editing; **Kerryn Butler-Henderson**: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review and editing; **Kristyn Harman**: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review and editing; **Joseph Crawford**: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review and editing.

Acknowledgements

The authors thank a senior lecturer from the College of Arts, Law and Education, who contributed to the full-text review stage and wishes to remain anonymous; and Zi-Ying Anna Cui for performing a second set of ratings of most of the included publications using the MMAT or QATTL.

References

(References marked with an asterisk indicate studies included in the systematic literature review.)

Aguayo, C., Cochrane, T., & Narayan, V. (2017). Key themes in mobile learning: Prospects for learner-generated learning through AR and VR. *Australasian Journal of Educational Technology*, *33*(6), 27–40. https://doi.org/10.14742/ajet.3671

*Akundi, A. (2017). Enhancing additive manufacturing education using virtual rapid prototyping simulator tool. In *Proceedings of the ASEE Annual Conference & Exposition* (pp. 10838–10861). American Society for Engineering Education. https://doi.org/10.18260/1-2--28271

*Alaeddine, N. I., Parsaei, H. R., Kakosimos, K., Guo, B., & Mansoor, B. (2015). Teaching innovation with technology to accelerate engineering students' learning. In *Proceedings of the ASEE Annual Conference & Exposition* (pp. 26.1478.1–26.1478.15). American Society for Engineering Education. https://doi.org/10.18260/p.24815

Allen, L. M., Hay, M., & Palermo, C. (2022). Evaluation in health professions education—Is measuring outcomes enough? *Medical Education*, *56*(1), 127–136. https://doi.org/10.1111/medu.14654

*Almeida, F. (2017). Experience with entrepreneurship learning using serious games. *Cypriot Journal of Educational Sciences*, *12*(2), 69–80. https://doi.org/10.18844/cjes.v12i2.1939

*Ambrosio Mawhirter, D., & Ford Garofalo, P. (2016). Expect the unexpected: Simulation games as a teaching strategy. *Clinical Simulation in Nursing*, *12*(4), 132–136. https://doi.org/10.1016/j.ecns.2015.12.009

*Andrew, L., Beverley, E., & Maslin-Prothero, S. (2015). Enhancing the online learning experience using virtual interactive classrooms. *Australian Journal of Advanced Nursing*, *32*(4), 22–31. https://www.ajan.com.au/archive/Vol32/Issue4/3Andrew.pdf

Appelbaum, M., Cooper, H., Kline, R. B., Mayo-Wilson, E., Nezu, A. M., & Rao, S. M. (2018). Journal article reporting standards for quantitative research in psychology: The APA Publications and Communications Board Task Force Report. *American Psychologist*, *73*(1). https://doi.org/10.1037/amp0000191

Arici, F., Yildirim, P., Caliklar, S., & Yilmaz, R. (2019). Research trends in the use of augmented reality in science education: Content and bibliographic mapping analysis. *Computers & Education*, *142*, Article 103647. https://doi.org/10.1016/j.compedu.2019.103647

*Asensio-Perez, J. I., Dimitriadis, Y., Pozzi, F., Hernandez-Leo, D., Prieto, L. P., Persico, D., & Villagra-Sobrino, S. L. (2017). Towards teaching as design: Exploring the interplay between full-lifecycle learning design tooling and teacher professional development. *Computers & Education*, *114*, 92–116. https://doi.org/10.1016/j.compedu.2017.06.011

*Astatke, Y., Ladeji-Osias, J. O., James, P., Moazzami, F., Scott, C., Connor, K., & Saka, A. (2015). Improving and expanding engineering education in the Middle East and Africa using mobile learning technology and innovative pedagogy. In M. Abdulwahed, M. Hasna, & J. Froyd (Eds.), *Advances in engineering education in the Middle East and North Africa* (pp. 235–260). Springer. https://doi.org/10.1007/978-3-319-15323-0_10

*Bardon, M., Ianna, T., Lee, A., Nolan, K., Salem, K., & Seibert, L. (2018). LANTITE: A driver for innovative literacy and numeracy practices. *Journal of Academic Language and Learning*, *12*(1), A254–A266. https://journal.aall.org.au/index.php/jall/article/view/527

*Barma, S., Daniel, S., Bacon, N., Gingras, M.-A., & Fortin, M. (2015). Observation and analysis of a classroom teaching and learning practice based on augmented reality and serious games on mobile platforms. *International Journal of Serious Games*, *2*(2), 69-88. https://doi.org/10.17083/ijsg.v2i2.66

*Barrette, C. M. (2015). Usefulness of technology adoption research in introducing an online workbook. *System*, *49*, 133–144. https://doi.org/10.1016/j.system.2015.01.005

Bedenlier, S., Bond, M., Buntins, K., Zawacki-Richter, O., & Kerres, M. (2020). Facilitating student engagement through educational technology in higher education: A systematic review in the field of arts and humanities. *Australasian Journal of Educational Technology*, *36*(4), 126–150. https://doi.org/10.14742/ajet.5477

*Bell, M., & Carr, P. (2014). Building communication skills for science students in videoconference tutorials. *International Journal of Innovation in Science and Mathematics Education*, *22*(4), 65–78. https://openjournals.library.sydney.edu.au/index.php/CAL/article/view/7570

Bennett, S., Lockyer, L., & Agostinho, S. (2018). Towards sustainable technology-enhanced innovation in higher education: Advancing learning design by understanding and supporting teacher design practice. *British Journal of Educational Technology*, *49*(6), 1014–1026. https://doi.org/10.1111/bjet.12683

*Bernaert, O., Crepon, R., & Dhorne, L. (2015). MOOC and serious game an educational approach on transfer and action. In *Diversity in engineering education: An opportunity to face the new trends of engineering—Proceedings of the 43rd Annual SEFI Conference* (pp. 1–8). European Society for Engineering Education. https://www.sefi.be/wp-content/uploads/2017/09/56077.-O.BERNAERT.pdf

*Bernardes, S., Madden, M., Knight, A., Neel, N., Morgan, N., Cameron, K., Knox, J. (2018). A multi-component system for data acquisition and visualization in the geosciences based on UAVs, augmented and virtual reality. *International Archives of the Photogrammetry*, *Remote Sensing and Spatial Information Sciences*, *42*(4), 45–49. https://doi.org/10.5194/isprs-archives-XLII-4-45-2018

*Biagioli, F. E., Elliot, D. L., Palmer, R. T., Graichen, C. C., Rdesinski, R. E., Ashok Kumar, K., Galper, A.B., & Tysinger, J. W. (2017). The electronic health record objective structured clinical examination: assessing student competency in patient interactions while using the electronic health record. *Academic Medicine*, *92*(1), 87–91. https://doi.org/10.1097/ACM.0000000000001276

*Blackburn, G. (2015). Innovative eLearning: Technology shaping contemporary problem based learning: A cross-case analysis. *Journal of University Teaching and Learning Practice*, *12*(2). https://doi.org/10.53761/1.12.2.5

Boelens, R., De Wever, B., & Voet, M. (2017). Four key challenges to the design of blended learning: A systematic literature review. *Educational Research Review*, *22*, 1–18. https://doi.org/10.1016/j.edurev.2017.06.001

*Boone, L., Ultee, L., Waisanen, E., Newell, J. P., Thorne, J. A., & Hardin, R. (2018). Collaborative creation and implementation of a Michigan sustainability case on urban farming in Detroit. *Case Studies in the Environment*, *2*(1), 1–13. https://doi.org/10.1525/cse.2017.000703

*Borras-Gene, O., Martinez-Nunez, M., & Fidalgo-Blanco, A. (2016). New challenges for the motivation and learning in engineering education using gamification in MOOC. *International Journal of Engineering Education*, *32*(1), 501–512. https://www.ijee.ie/contents/c320116B.html

Boshier, R. (2009). Why is the scholarship of teaching and learning such a hard sell? *Higher Education Research & Development*, *28*(1), 1–15. https://doi.org/10.1080/07294360802444321

*Bousmah, M., Labouidya, O., & El Kamoun, N., (2015). Design of a cloud learning system based on multi-agents approach. *International Journal of Advanced Computer Science and Applications*, *6*(3), 20–26. https://thesai.org/Downloads/Volume6No3/Paper_3-Design_of_a_Cloud_Learning_System_Based.pdf

*Bower, M., Lee, M. J. W., & Dalgarno, B. (2017). Collaborative learning across physical and virtual worlds: Factors supporting and constraining learners in a blended reality environment. *British Journal of Educational Technology*, *48*(2), 407–430. https://doi.org/10.1111/bjet.12435

*Bridges, S., Chang, J. W. W., Chu, C. H., & Gardner, K. (2014). Blended learning in situated contexts: 3-year evaluation of an online peer review project. *European Journal of Dental Education*, *18*(3), 170–179. https://doi.org/10.1111/eje.12082

*Bryant, P. (2017). Generating learning through the crowd: The role of social media practices in supporting students as producers at scale. In H. Partridge, K. Davis, & J. Thomas (Eds.), *Me, us, IT!—Proceedings of the 34th International Conference of Innovation, Practice and Research in the Use of Educational Technologies in Tertiary Education* (pp. 197–207). Australasian Society for Computers in Learning in Tertiary Education. https://2017conference.ascilite.org/wp-content/uploads/2017/11/ASCILITE-2017-Proceeding.pdf

*Bujdosó, G., Novac, O. C., & Szimkovics, T. (2017). Developing cognitive processes for improving inventive thinking in system development using a collaborative virtual reality system. In *Proceedings of the 8th IEEE International Conference on Cognitive Infocommunications* (pp. 79–84). IEEE. https://doi.org/10.1109/CogInfoCom.2017.8268220

Butler-Henderson, K., Tan, S., Lalani, K., Mandapam, S. K., Kemp, T., Rudolph, J., & Crawford, J. (2021). Update of the COVID-19 Higher Education Literature Database (CHELD v2). *Journal of Applied Learning & Teaching*, *4*(1), 1–4. https://doi.org/10.37074/jalt.2021.4.1.22

*Caldwell, H., & Heaton, R. (2016). The interdisciplinary use of blogs and online communities in teacher education. *International Journal of Information and Learning Technology*, *33*(3), 142–158. https://doi.org/10.1108/ijilt-01-2016-0006

*Calvo Salvador, A., & Rodríguez-Hoyos, C. (2016). Analizying [sic] MOOCs from an educational perspective in Spain. *International Journal of Educational Technology in Higher Education*, *13*(1), 1–10. https://doi.org/10.1186/s41239-016-0005-2

Castillo-Manzano, J. I., Castro-Nuño, M., López-Valpuesta, L., Sanz-Díaz, M. T., & Yñiguez, R. (2016). Measuring the effect of ARS on academic performance: A global meta-analysis. *Computers & Education*, *96*, 109–121. https://doi.org/10.1016/j.compedu.2016.02.007

*Celik, H., Sari, U., & Harwanto, U. N. (2015). Evaluating and developing physics teaching material with Algodoo in virtual environment: Archimedes' principle. *International Journal of Innovation in Science and Mathematics Education*, *23*(4), 40–50. https://openjournals.library.sydney.edu.au/index.php/CAL/article/view/8084

*Chan, T. M., Thoma, B., & Lin, M. (2015). Creating, curating, and sharing online faculty development resources: The medical education in cases series experience. *Academic Medicine*, *90*(6), 785–789. https://doi.org/10.1097/ACM.0000000000000692

*Chanprasitchai, O., & Khlaisang, J. (2016). Inquiry-based learning for a virtual learning community to enhance problem-solving ability of applied Thai traditional medicine students. *Turkish Online Journal of Educational Technology*, *15*(4), 77–87. http://www.tojet.net/articles/v15i4/1549.pdf

*Cheng, J., Wang, Y., Tjondronegoro, D., & Song, W. (2018). Construction of interactive teaching system for course of mechanical drawing based on mobile augmented reality technology. *International Journal of Emerging Technologies in Learning*, *13*(2), 126–139. https://doi.org/10.3991/ijet.v13i02.7847

*Cheung, G., Wan, K., & Chan, K. (2018). Efficient use of clickers: A mixed-method inquiry with university teachers. *Education Sciences*, *8*(1), Article 31. https://doi.org/10.3390/educsci8010031

*Chiang, C.-W., & Liu, J.-W. (2019). A study of the interactive styles of an augmented reality system for cultural innovative product design. In J. C. Hung, N. Y. Yen, & L. Hui (Eds.), *Lecture notes in electrical engineering: Vol. 542. Frontier computing: Theory, technologies and applications* (pp. 640–646). Springer. https://doi.org/10.1007/978-981-13-3648-5_78

Chien, Y. T., Chang, Y. H., & Chang, C. Y. (2016). Do we click in the right way? A meta-analytic review of clicker-integrated instruction. *Educational Research Review*, *17*, 1–8. https://doi.org/10.1016/j.edurev.2015.10.003

*Chua, X. N., & Chew, E. (2015). The next wave of learning with humanoid robot: learning innovation design starts with “Hello NAO”. In T. Reiners, B. R. von Konsky, D. Gibson, V. Chang, L. Irving, & K. Clarke (Eds.), *Globally connected, digitally enabled—Proceedings of the 2015 ASCILITE Conference*

(pp. 404–408). Australasian Society for Computers in Learning in Tertiary Education. http://www.2015conference.ascilite.org/wp-content/uploads/2015/11/ascilite-2015-proceedings.pdf
Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research*, *86*(1), 79–122. https://doi.org/10.3102/0034654315582065
Clunie, L., Morris, N. P., Joynes, V. C. T., & Pickering, J. D. (2018). How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? A systematic review. *Anatomical Sciences Education*, *11*(3), 303–319. https://doi.org/10.1002/ase.1762
*Cobley, J., & Steven, B. (2014). Using Web 2.0 technologies to enhance speaking fluency: A journey beyond textbooks. *Research Notes (Cambridge Assessment English)*, *56*, 36–44. https://www.cambridgeenglish.org/Images/170903-research-notes-56-document.pdf
*Collins, L., Sicks, S., Umland, E., & Phillips, J. D. (2019). A tool for assessing interprofessional collaborative practice: Evolution of the Jefferson Teamwork Observation Guide (JTOG)(R). *Journal of Interprofessional Care*. Advance online publication. https://doi.org/10.1080/13561820.2019.1613967
*Colombo, A., & Gomez Pradas, M. (2014). SIMULACRE: A proposal for practical training in e learning environments. *RUSC Universities and Knowledge Society Journal*, *11*(3), 4–21. https://doi.org/10.7238/rusc.v11i3.1781
Cook, D. A., & Ellaway, R. H. (2015). Evaluating technology-enhanced learning: a comprehensive framework. *Medical Teacher*, *37*(10), 961–970. https://doi.org/10.3109/0142159X.2015.1009024
*Cooper, T., & Scriven, R. (2017). Communities of inquiry in curriculum approach to online learning: Strengths and limitations in context. *Australasian Journal of Educational Technology*, *33*(4), 22–37. https://doi.org/10.14742/ajet.3026
*Cozar-Gutierrez, R., & Saez-Lopez, J. M. (2016). Game-based learning and gamification in initial teacher training in the social sciences: An experiment with MinecraftEdu. *International Journal of Educational Technology in Higher Education*, *13*, Article 2. https://doi.org/10.1186/s41239-016-0003-4
Crawford, J., Butler-Henderson, K., Rudolph, J., Malkawi, B., Glowatz, M., Burton, R., Magni, P. A., & Lam, S. (2020). COVID-19: 20 countries' higher education intra-period digital pedagogy responses. *Journal of Applied Learning & Teaching*, *3*(1), 9–28. https://doi.org/10.37074/jalt.2020.3.1.7
Crawford, J., Kelder, J-A., & Wilson, G. (2023). *Quality assessment tool for theory-based and literature review studies (QATTL): Development and validation of a critical appraisal tool* [Unpublished manuscript]. Department of Management, Tasmanian School of Business and Economics, University of Tasmania.
*Dai, G., Liu, Y., & Cui, S. (2018). A study on the mobile learning of English and American literature based on WeChat public account. *English Language Teaching*, *11*(6), 47–66. https://doi.org/10.5539/elt.v11n6p47
*Daineko, Y., Dmitriyev, V., & Ipalakova, M. (2017). Using virtual laboratories in teaching natural sciences: An example of physics courses in university. *Computer Applications in Engineering Education*, *25*(1), 39–47. https://doi.org/10.1002/cae.21777
Davis, D., Chen, G., Hauff, C., & Houben, G.-J. (2018). Activating learning at scale: A review of innovations in online learning strategies. *Computers & Education*, *125*, 327–344. https://doi.org/10.1016/j.compedu.2018.05.019
*Deng, Y., Lu, D., Chung, C.-J., Huang, D., & Zeng, Z. (2018). Personalized learning in a virtual hands-on lab platform for computer science education. In *Fostering innovation through diversity—Proceedings of the 2018 Frontiers in Education Conference* (pp. 1–8). IEEE. https://doi.org/10.1109/FIE.2018.8659291
*de Oliveira Durso, S., Reginato, L., & Cornacchione, E. (2019). Gamification in accounting and students' skillset. *Advances in Scientific & Applied Accounting*, *12*(3), 79–100. https://doi.org/10.14392/asaa.2019120305

*De Ville, J., Saldien, J., Conradie, P., & Vandevelde, C. (2016). Prototyping tangible user interfaces: Case study of the collaboration between academia and industry. *International Journal of Engineering Education*, *32*(2), 726–737. https://www.ijee.ie/contents/c320216A.html

*Dobinson, T., & Stokes-Thompson, F. (2015). The potential for utilising the collaborative learning spaces approach in the delivery of resume development education. *Australian Journal of Career Development*, *24*(1), 64–68. https://doi.org/10.1177/1038416214565671

*Donnelly, R. (2019). Supporting pedagogic innovators in professional practice through applied eLearning. *E-Learning and Digital Media*, *16*(4), 301–327. https://doi.org/10.1177/2042753019836317

*Drury, H., & Muir, M. (2014). Using an e-learning environment for developing science students' written communication: The case of writing laboratory reports in physiology. *International Journal of Innovation in Science and Mathematics Education*, *22*(4), 79–93. https://openjournals.library.sydney.edu.au/index.php/CAL/article/view/7592

*Dune, T., Bidewell, J., Firdaus, R., & Kirwan, M. (2016). Communication idol: Using popular culture to catalyse active learning by engaging students in the development of entertaining teaching and learning resources. *Journal of University Teaching & Learning Practice*, *13*(5). https://ro.uow.edu.au/cgi/viewcontent.cgi?article=1665&context=jutlp

*Durak, G., Ozkeskin, E. E., & Ataizi, M. (2016). QR codes in education and communication. *Turkish Online Journal of Distance Education*, *17*(2), 42–58. https://dergipark.org.tr/en/download/article-file/222605

*Eady, M. J., Jones, M. L., Alony, I., & Berry, Y. (2018). Rights, respect and responsibilities online: Reflections and efficacy. *Australian Journal of Teacher Education*, *43*(3), 35–54. https://doi.org/10.14221/ajte.2018v43n3.3

*Edmonds, R., & Smith, S. (2017). From playing to designing: Enhancing educational experiences with location-based mobile learning games. *Australasian Journal of Educational Technology*, *33*(6), 41–53. https://doi.org/10.14742/ajet.3583

*Eliche-Quesada, D., La Rubia, M. A., Rus-Casas, C., Aguilar-Peña, J. D., & Pérez-Villarejo, L. (2016). Web 2.0 and social networking tools for the materials science teaching-learning process. In L. Gómez Chova, A. López Martínez, & I. Candel Torres (Eds.), *Proceedings of the 9th Annual International Conference of Education, Research and Innovation* (pp. 7751–7758). IATED Academy. https://doi.org/10.21125/iceri.2016.0777

*Espejo-Trung, L. C., Elian, S. N., & De Cerqueira Luz, M. A. A. (2015). Development and application of a new learning object for teaching operative dentistry using augmented reality. *Journal of Dental Education*, *79*(11), 1356–1362. https://doi.org/10.1002/j.0022-0337.2015.79.11.tb06033.x

*Fadzil, H. M. (2018). Designing infographics for the educational technology course: Perspectives of pre-service science teachers. *Journal of Baltic Science Education*, *17*(1), 8–18. https://doi.org/10.33225/jbse/18.17.08

*Fahara, M. F., & Castro, A. L. (2015). Teaching strategies to promote immediacy in online graduate courses, *Open Praxis*, *7*(4), 363–376. https://doi.org/10.5944/openpraxis.7.4.228

*Farouk, S. S., Hilburg, R., & Sparks, M. A. (2019). Design, dissemination, and assessment of NephSIM: A mobile-optimized nephrology teaching tool. *Journal of Graduate Medical Education*, *11*(6), 708–712. https://doi.org/10.4300/JGME-D-19-00443.1

*Felszeghy, S., Pasonen-Seppänen, S., Koskela, A., Nieminen, P., Härkönen, K., Paldanius, K. M. A., Gabbouj, S., Ketola, K., Hiltunen, M., Lundin, M., Haapaniemi, T., Sointu, E., Bauman, E. B., Gilbert, G. E., Morton, D., & Mahonen, A. (2019). Using online game-based platforms to improve student performance and engagement in histology teaching. *BMC Medical Education*, *19*, Article 273. https://doi.org/10.1186/s12909-019-1701-0

*Ferguson, K. J., Kreiter, C. D., Haugen, T. H., & Dee, F. R. (2018). Web-enabled mechanistic case diagramming: A novel tool for assessing students' ability to integrate foundational and clinical sciences. *Academic Medicine*, *93*(8), 1146–1149. https://doi.org/10.1097/ACM.0000000000002184

*Fernandez-Ferrer, M., & Cano, E. (2016). The influence of the internet for pedagogical innovation: using twitter to promote online collaborative learning. *International Journal of Educational Technology in Higher Education*, *13*, Article 22. https://doi.org/10.1186/s41239-016-0021-2

*Feshchenko, A., Mozhaeva, G., Kulikov, I., & Zilberman, N. (2015). Prospects for the development of e-learning technologies. In M. Helfert, M. T. Restivo, S. Zvacek, & J. Uhomoibhi (Eds.), *Proceedings of the 7th International Conference on Computer Supported Education* (Vol. 1 , pp. 208–212). SciTePress. https://doi.org/10.5220/0005410102080212

*Fleischmann, K. (2019). From studio practice to online design education: Can we teach design online? *Canadian Journal of Learning and Technology*, *45*(1). https://doi.org/10.21432/cjlt27849

*Foronda, C., Budhathoki, C., & Salani, D. (2014). Use of multiuser, high-fidelity virtual simulation to teach leadership styles to nursing students. *Nurse Educator*, *39*(5), 209–211. https://doi.org/10.1097/NNE.0000000000000073

*Franqueira, T., & Gomes, G. (2017). Design for social innovation supported by social based technologies. In N. Streitz & P. Markopoulos (Eds.), *Lecture notes in computer science: Vol. 10291. Distributed, ambient, and pervasive interactions* (pp. 45–60). Springer. https://doi.org/10.1007/978-3-319-58697-7_4

*Freguia, S. (2017). Webcasts promote in-class active participation and learning in an engineering elective course. *European Journal of Engineering Education*, *42*(5), 482–492. https://doi.org/10.1080/03043797.2016.1192110

*Gamo, J. (2019). Assessing a virtual laboratory in optics as a complement to on-site teaching. *IEEE Transactions on Education*, *62*(2), 119–126. https://doi.org/10.1109/te.2018.2871617

*García-Ruiz, R., Gonzalez Fernández, N., & Contreras Pulido, P. (2014). Competency training in universities via projects and Web 2.0 tools. Analysis of an experience. *RUSC Universities and Knowledge Society Journal*, *11*(1), 61–75. https://doi.org/10.7238/rusc.v11i1.1713

Garrison, D. R., Anderson, T., & Archer, W. (2010). The first decade of the community of inquiry framework: A retrospective. *The Internet and Higher Education*, *13*(1-2), 5–9. https://doi.org/10.1016/j.iheduc.2009.10.003

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. *Educational Research Review*, *27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Ge, X., Turk, M., & Hung, W. (2019). Revisiting cognitive tools from a social and motivational perspective. *Australasian Journal of Educational Technology*, *35*(2), 39–51. https://doi.org/10.14742/ajet.4887

*Gillham, D., Tucker, K., Parker, S., Wright, V., & Kargillis, C. (2015). CaseWorld (TM): Interactive, media rich, multidisciplinary case based learning. *Nurse Education in Practice*, *15*(6), 567–571. https://doi.org/10.1016/j.nepr.2015.10.003

*Gil Ortega, M. C., & Falconer, L. (2015). Learning spaces in virtual worlds: bringing our distance students home. *Journal of Applied Research in Higher Education*, *7*(1), 83–98. https://doi.org/10.1108/JARHE-02-2014-0026

Goodyear, P. (2015). Teaching as design. *HERDSA Review of Higher Education*, *2*(2), 27–50. https://www.herdsa.org.au/herdsa-review-higher-education-vol-2/27-50

*Gordon, E., & Dodman, T. (2014). Mobile learning in security, conflict and international development: Giving busy people the flexibility to study on the move. In L. Gómez Chova, A. López Martínez, & I. Candel Torres (Eds.), *Proceedings of the 8th Annual International Conference of Technology, Education and Development* (pp. 5166–5174). IATED Academy. https://library.iated.org/view/GORDON2014MOB

*Graham, L., & Fredenberg, V. (2015). Impact of an open online course on the connectivist behaviours of Alaska teachers. *Australasian Journal of Educational Technology*, *31*(2), 140–149. https://doi.org/10.14742/ajet.1476

Grimwood, T., & Snell, L. (2020). The use of technology in healthcare education: A literature review. *MedEdPublish*, *9*(1), 137. https://doi.org/10.15694/mep.2020.000137.1

*Guariento, B., Almasri, N. A.-S., & Rolinska, A. (2016). Investigating EAST (A Scotland-Gaza English for academic study telecollaboration between SET students). In *Proceedings of the ASEE Annual Conference & Exposition* (pp. 1–23). American Society for Engineering Education. https://doi.org/10.18260/p.25472

*Guinau Sellés, M., Playà Pous, E., Aulinas Juncà, M., Rosell Ortiz, L., & Rivero Marginedas, L. (2017). Improving transversal competences by using wikis in collaborative work. *Journal of Technology and Science Education*, *7*(2), 172–183. https://doi.org/10.3926/jotse.248

Halverson, E. R., & Sheridan, K. M. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4), 495–504. https://doi.org/10.17763/haer.84.4.34j1g68140382063

*Hanbidge, A. S., Sanderson, N., & Tin, T. (2015). Using mobile technology to enhance undergraduate student digital information literacy skills: A Canadian case study. *IAFOR Journal of Education*, *3*, 108–121. https://doi.org/10.22492/ije.3.se.07

*Hasan, H. F., Nat, M., & Vanduhe, V. Z. (2019). Gamified collaborative environment in Moodle. *IEEE Access*, *7*, 89833–89844. https://ieeexplore.ieee.org/abstract/document/8754666

*Hassoulas, A., Forty, E., Hoskins, M., Walters, J., & Riley, S. (2017). A case-based medical curriculum for the 21st century: The use of innovative approaches in designing and developing a case on mental health. *Medical Teacher*, *39*(5), 505–511. https://doi.org/10.1080/0142159X.2017.1296564

Heradio, R., de la Torre, L., Galan, D., Cabrerizo, F. J., Herrara-Viedma, E., & Dormido, S. (2016). Virtual and remote labs in education: A bibliometric analysis. *Computers & Education*, *98*, 14–38. https://doi.org/10.1016/j.compedu.2016.03.010

*Hernandez-de-Menendez, M., Guevara, A. V., & Morales-Menendez, R. (2019). Virtual reality laboratories: A review of experiences. *International Journal of Interactive Design and Manufacturing*, *13*(3), 947–966. https://doi.org/10.1007/s12008-019-00558-7

*Hesterman, S. (2016). The digital handshake: A group contract for authentic elearning in higher education. *Journal of University Teaching & Learning Practice*, *13*(3). https://doi.org/10.53761/1.13.3.6

Hew, K., Bai, S., Huang, W., Dawson, P., Du, J., Huang, G., Jia, C., & Thankrit, K. (2021). On the use of flipped classroom across various disciplines: Insights from a second-order meta-analysis. *Australasian Journal of Educational Technology*, *37*(2), 132–151. https://doi.org/10.14742/ajet.6475

*Hilliard, I. (2014). People power – Computer games in the classroom. *Higher Learning Research Communications*, *4*(1), 112–121. https://doi.org/10.18870/hlrc.v4i1.200

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, M. (2020, March 27). The difference between emergency remote teaching and online learning. *Educause Review*. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

*Holmes, M. R., Tracy, E. M., Painter, L. L., Oestreich, T., & Park, H. (2015). Moving from flipcharts to the flipped classroom: Using technology driven teaching methods to promote active learning in foundation and advanced masters social work courses. *Clinical Social Work Journal*, *43*(2), 215–224. https://doi.org/10.1007/s10615-015-0521-x

Hong, Q., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., & Vedel, I. (2018). *Mixed Methods Appraisal Tool (MMAT) version 2018 user guide*. McGill University. http://mixedmethodsappraisaltoolpublic.pbworks.com/w/file/146002140/MMAT_2018_criteria-manual_2018-08-08c.pdf

Hunsu, N. J., Adesope, O., & Bayly, D. J. (2016). A meta-analysis of the effects of audience response systems (clicker-based technologies) on cognition and affect. *Computers & Education*, *94*, 102–119. https://doi.org/10.1016/j.compedu.2015.11.013

*Intriago, E., Villafuerte, J. S., Jaramillo, M. A. M., Lema, A., & Echeverria, J. (2016). Google apps for virtual learning communities development: Strengthening English language skills in an university environment. *AtoZ: Novas Práticas Em Informação E Conhecimento*, *5*(1), 21–32. https://doi.org/10.5380/atoz.v5i1.45170

*James, F., Figaro-Henry, S., Wickham, L., Aaltio, I., & Eskelinen, M. (2016). Virtual spaces impacting real places: Entrepreneurial innovations in Trinidad and Tobago's tertiary education landscape. In M. T. Eskelinen & I. Aalito (Eds.), *Proceedings of the 11th European Conference on Innovation and Entrepreneurship* (pp. 320–327). Academic Conferences and Publishing International Ltd.

*Jauregui, J., Bright, S., Strote, J., & Shandro, J. (2018). A novel approach to medical student peer-assisted learning through case-based simulations. *Western Journal of Emergency Medicine*, *19*(1), 193–197. https://doi.org/10.5811/westjem.2017.10.35319

Kaliisa, R., & Picard, M. (2019). Mobile learning policy and practice in Africa: Towards inclusive and equitable access to higher education. *Australasian Journal of Educational Technology*, *35*(6), 1–14. https://doi.org/10.14742/ajet.5562

*Keckstein, T., Votápek, P., Jirásko, J. (2016). Evaluation of e-learning materials created at the University of West Bohemia. In R. M. Idrus & N. Zainuddin (Eds.), *Proceedings of the 11th International Conference on E-learning* (pp. 74–78). Academic Conferences and Publishing International Ltd.

*Kelly, N., Russell, N., Kickbusch, S., Barros, A., Dawes, L., & Rasmussen, R. (2018). Online communities of teachers to support situational knowledge: A design-based study. *Australasian Journal of Educational Technology*, *34*(5), 150–166. https://doi.org/10.14742/ajet.3867

*Khlaisang, J., & Songkram, N. (2019). Designing a virtual learning environment system for teaching twenty-first century skills to higher education students in ASEAN. *Technology, Knowledge and Learning*, *24*(1), 41–63. https://doi.org/10.1007/s10758-017-9310-7

*Kim, D., & Jang, S. E. (2014). Dialogic practices in using podcasting and blogging as teaching tools for teachers seeking ESOL certificate. *Journal of Educational Computing Research*, *51*(2), 205–232. https://doi.org/10.2190/EC.51.2.d

Kirkwood, A., & Price, L. (2014). Technology-enhanced learning and teaching in higher education: What is “enhanced” and how do we know? A critical literature review. *Learning, Media and Technology*, *39*(1), 6–36. https://doi.org/10.1080/17439884.2013.770404

*Kreniske P., Pala, A. N., Milman, R., & Sanchez C. (2019). Expressive innovation: How first-year college students introduced emoticons to the curriculum. *Cognitive Development*, *49*, 105–115. https://doi.org/10.1016/j.cogdev.2018.11.003

*Kruger, A. (2017). Ahead of the e-curve in fact checking and verification education: The University of Hong Kong's cyber news verification lab leads verification education in Asia. *Asia Pacific Media Educator*, *27*(2), 264–281. https://doi.org/10.1177/1326365X17736579

*Landorf, C., Brewer, G., Maund, K., & Ward, S. (2015). Enhancing learning for construction industry professionals with a 4-dimensional digital learning environment. In *Learning for life and work in a complex world—Proceedings of the HERDSA Annual International Conference* (Vol. 38, pp. 279–290). Higher Education Research and Development Society of Australasia. https://www.herdsa.org.au/publications/conference-proceedings/research-and-development-higher-education-learning-life-and-24

Lee, D., Watson, S. L., & Watson, W. R. (2019). Systematic literature review on self-regulated learning in massive open online courses. *Australasian Journal of Educational Technology*, *35*(1), 28–41. https://doi.org/10.14742/ajet.3749

*Lee, J. H., & Shvetsova, O. A. (2019). The impact of VR application on student's competency development: A comparative study of regular and VR engineering classes with similar competency scopes, *Sustainability*, *11*(8), Article 2221. https://doi.org/10.3390/su11082221

Levitt, H. M., Bamberg, M., Creswell, J. W., Frost, D. M., Josselson, R., & Suárez-Orozco, C. (2018). Journal article reporting standards for qualitative primary, qualitative meta-analytic, and mixed methods research in psychology: The APA Publications and Communications Board Task Force Report. *American Psychologist*, *73*(1), 26–46. https://psycnet.apa.org/fulltext/2018-00750-003.html

*Li, C., Fu, L., & Wang, L. (2018). Innovate engineering education by using virtual laboratory platform based industrial robot. In *Proceedings of the 30th Chinese Control and Decision Conference* (pp. 3467–3472). IEEE. https://doi.org/10.1109/CCDC.2018.8407723

*Lim, R. M., Novo de Azevedo, L., & Cooper, J. (2016). Embracing the conceptual shift on new ways of experiencing the city and learning urban design: Pedagogical methods and digital technologies, *Journal of Urban Design*, *21*(5), 638–660. https://doi.org/10.1080/13574809.2015.1071651

Liyanagunawardena, T. R., Adams, A. A., & Williams, S. A. (2013). MOOCs: A systematic study of the published literature 2008–2012. *The International Review of Research in Open and Distributed Learning*, *14*(3), 202–227. https://doi.org/10.19173/irrodl.v14i3.1455

*Marin, V., Negre, F., Perez, A., & de Mallorca, D. (2014). Entornos y redes personales de aprendizaje (PLE-PLN) para el aprendizaje colaborativo [Construction of the foundations of the PLE and PLN for collaborative learning]. *Comunicar*, *21*(42), 35–43. https://doi.org/10.3916/c42-2014-03

*Martins, M. (2015). How to effectively integrate technology in the foreign language classroom for learning and collaboration. *Procedia – Social and Behavioural Sciences*, *174*, 77–84. https://doi.org/10.1016/j.sbspro.2015.01.629

*Matthew, A. F., & Butler, D. (2017). Narrative, machinima and cognitive realism: Constructing an authentic real-world learning experience for law students. *Australasian Journal of Educational Technology*, *33*(1), 148–162. https://doi.org/10.14742/ajet.2846
*McCarthy, J. (2014). Multicultural learning partnerships in the Cafe: Integrating ICT into transnational tertiary education in Australia using the collaborative application for education. *Journal of International and Comparative Education*, *3*(2), 173–184. https://doi.org/10.14425/00.73.59
*McCarthy, J. (2015). Learning in the Café: Pilot testing the collaborative application for education in Facebook. *Australasian Journal of Educational Technology*, *31*(1), 67–85. https://doi.org/10.14742/ajet.1500
*McGuinness, C., & Fulton, C. (2019). Digital literacy in higher education: A case study of student engagement with e-tutorials using blended learning. *Journal of Information Technology Education: Innovations in Practice*, *18*, 1–28. https://doi.org/10.28945/4190
*McLaughlin, J. E., White, P. J., Khanova, J., & Yuriev, E. (2016). Flipped classroom implementation: A case report of two higher education institutions in the United States and Australia. *Computers in the Schools*, *33*(1), 24–37. https://doi.org/10.1080/07380569.2016.1137734
*Miao, G., Clarke, S., Mammucari, R., & Parker, L. (2018). Thinking outside of the (augmented reality sand)box. In *Proceedings of the Australasian Association for Engineering Education 29th Annual Conference* (pp. 502–507). Engineers Australia. http://18aaee.s3.amazonaws.com/proceedings/AAEE18_Miao_76.pdf
Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. https://journals.sagepub.com/doi/pdf/10.1111/j.1467-9620.2006.00684.x
*Mlitwa, N. W. B., & Wanyonyi, D. W. (2015). Towards interactive open source based m-Learning solution: The m-Chisimba framework. *Journal of Engineering, Design and Technology*, *13*(3), 463–485. https://doi.org/10.1108/jedt-08-2013-0059
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), Article e1000097. https://doi.org/10.1371/journal.pmed.1000097
*Mosalanejad, L., & Abdollahifard, S. (2018). Gamification in psychiatry: Design and development of native model and the innovate strategy in medical education as a funny and exciting learning. *Pakistan Journal of Medical & Health Sciences*, *12*(4), 1820–1828. https://pjmhsonline.com/2018/oct_dec/pdf/1820.pdf
*Nallaya, S., Delaney, B., Savelsberg, H., & Lancione, C. (2018). Developing a self-regulated curricula of scaffolded academic and information literacies in a digital learning environment. *Journal of Academic Language & Learning*, *12*(1), A179–A192. https://journal.aall.org.au/index.php/jall/article/view/517
*Ngai, C. S. B., Lee, W. M., Ng, P. P. K., & Wu, D. D. (2019). Innovating an integrated approach to collaborative eLearning practices in higher education: The case study of a corporate communication e-platform. *Studies in Higher Education*, *44*(11), 1990–2010. https://doi.org/10.1080/03075079.2018.1482266
O'Brien, B. C., Harris, I. B., Beckman, T. J., Reed, D. A., & Cook, D. A. (2014). Standards for reporting qualitative research: A synthesis of recommendations. *Academic Medicine*, *89*(9), 1245–1251. https://doi.org/10.1097/ACM.0000000000000388
*Okada, A., Kowalski, R. P. G., Kirner, C., & Torres, P. L. (2019). Factors influencing teachers' adoption of AR inquiry games to foster skills for responsible research and innovation. *Interactive Learning Environments*, *27*(3), 324–335. https://doi.org/10.1080/10494820.2018.1473257
*Padilha, J. M., Machado, P. P., Ribeiro, A., Ramos, J., & Costa, P. (2019). Clinical virtual simulation in nursing education: Randomized controlled trial. *Journal of Medical Internet Research*, *21*(3), Article e11529. https://doi.org/10.2196/11529
Palalas, A., & Wark, N. (2020). The relationship between mobile learning and learner self-regulation: A systematic review. *Australasian Journal of Educational Technology*, *36*(4), 151–172. https://doi.org/10.14742/ajet.5650
*Patiar, A., Ma, E., Kensbock, S., & Cox, R. (2017). Hospitality management students' expectation and perception of a virtual field trip web site: An Australian case study using importance-performance

analysis. *Journal of Hospitality & Tourism Education*, *29*(1), 1–12. https://doi.org/10.1080/10963758.2016.1266941

*Patil, R. N., Almale, B. D., Patil, M., Gujrathi, A., Dhakne-Palwe, S., Patil, A. R., & Gosavi, S. (2016). Attitudes and perceptions of medical undergraduates towards mobile learning (m-learning). *Journal of Clinical and Diagnostic Research*, *10*(10), JC06–JC10. https://doi.org/10.7860/JCDR/2016/20214.8682

*Peñalvo, F. J. G., Cruz-Benito, J., Conde, M. Á., & Griffiths, D. (2015). Semester of code: Piloting virtual placements for informatics across Europe. In *Engineering education towards excellence and innovation—Proceedings of the 2015 IEEE Global Engineering Education Conference* (pp. 567–576). IEEE. https://doi.org/10.1109/EDUCON.2015.7096026

*Phon, D. N. E., Ali, M. B., & Abd Halim, N. D. (2014). Collaborative augmented reality in education: A review. In *Proceedings of the 2014 International Conference on Teaching and Learning in Computing and Engineering* (pp. 78–83). IEEE. https://doi.org/10.1109/LaTiCE.2014.23

*Pinya, C., & Rossello, M. R. (2016). Using blogs to be aware of the development and adoption of professional skills. *Education and Information Technologies*, *21*(5), 1055–1070. https://doi.org/10.1007/s10639-014-9367-z

*Poce, A., Agrusti, F., & Re, M. R. (2018). Heritage education and initial teacher training: An international experience. *Journal of e-Learning and Knowledge Society*, *14*(2), 127–143. https://doi.org/10.20368/1971-8829/1488

Praslova L. (2010). Adaptation of Kirkpatrick's four level model of training criteria to assessment of learning outcomes and program evaluation in higher education. *Educational Assessment, Evaluation and Accountability*, *22*(3), 215–25. https://doi.org/10.1007/s11092-010-9098-7

*Price, D., Strodtman, L., Brough, E., Lonn, S., & Luo, A. (2015). Digital storytelling: An innovative technological approach to nursing education. *Nurse Educator*, *40*(2), 66–70. https://doi.org/10.1097/NNE.0000000000000094

*Quinn, D., Cioffi, E., Hill, S., Kor, M., Longford, A.-C., Moller, R., & Rathore, P. (2019). Implementing work-integrated learning in online construction management courses. *Journal of University Teaching and Learning Practice*, *16*(1). https://doi.org/10.53761/1.16.1.9

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147,* Article 103778. https://doi.org/10.1016/j.compedu.2019.103778

*Ramírez-Donoso, L., Rojas-Riethmuller, J. S., Pérez-Sanagustín, M., & Neyem, A. (2017). Enhancing collaborative learning in higher education online courses through a mobile game app. In W. Shen, P. Antunes, N. G. Thuan, J.-P. Barthès, J. Luo, & J. Yong (Eds.), *Proceedings of the 21st International Conference on Computer Supported Cooperative Work in Design* (pp. 103–108). IEEE. https://doi.org/10.1109/CSCWD.2017.8066678

*Reidsema, C., Kavanagh, L., Fink, E., Long, P., & Smith, N. (2014). The learning pathway: Online navigational support for students within the structured flipped classroom. In A. Bainbridge-Smith, Z. T. Qi, & G. Sen Gupta (Eds.), *Engineering the knowledge economy: Collaboration, engagement & employability—Proceedings of the 25th Annual Conference of the Australasian Association for Engineering Education* (pp. 788–795). Massey University. https://aaee.net.au/wp-content/uploads/2018/10/AAEE2014-Reidsema_Kavanagh_Fink_et_al-Online_navigational_support_within_structured_flipped_classroom.pdf

Rodríguez-Hoyos, C., Salmón, I. H., & Fernández-Díaz, E. (2015). Research on SNS and education: The state of the art and its challenges. *Australasian Journal of Educational Technology*, *31*(1), 100–111. https://doi.org/10.14742/ajet.995

*Romero-Rodríguez, L. M., Ramirez-Montoya, M. S., & Gonzalez, J. R. V. (2019). Gamification in MOOCs: Engagement application test in energy sustainability courses. *IEEE Access*, *7*, 32093–32101. https://doi.org/10.1109/access.2019.2903230

*Sadowski, C., Pediaditis, M., & Townsend, R. (2017). University students' perceptions of social networking sites (SNSs) in their educational experiences at a regional Australian university. *Australasian Journal of Educational Technology*, *33*(5), 77–90. https://doi.org/10.14742/ajet.2927

Saikat, S., Dhillon, J. S., Wan Ahmad, W. P., & Jamaluddin, R. A. (2021). A systematic review of the benefits and challenges of mobile learning during the COVID-19 pandemic. *Education Sciences*, *11*(9), Article 459. https://doi.org/10.3390/educsci11090459

*Salmon, G., Ross, B., Pechenkina, E., & Chase, A.-M. (2015). The space for social media in structured online learning. *Research in Learning Technology*, *23*, Article 28507. https://doi.org/10.3402/rlt.v23.28507

*Sari, U., Pektas, H. M., Çelik, H., & Kirindi, T. (2019). The effects of virtual and computer based real laboratory applications on the attitude, motivation and graphic skills of university students. *International Journal of Innovation in Science and Mathematics Education*, *27*(1), 1–17. https://doi.org/10.30722/IJISME.27.01.001

Saubern, R., Henderson, M., Heinrich, E., & Redmond, P. (2020). TPACK–time to reboot? *Australasian Journal of Educational Technology*, *36*(3), 1–9. https://doi.org/10.14742/ajet.6378

*Scamell, M., & Hanley, T. (2017). Innovation in preregistration midwifery education: Web based interactive storytelling learning. *Midwifery*, *50*, 93–98. https://doi.org/10.1016/j.midw.2017.03.016

Shen, C., & Ho, J. (2020). Technology-enhanced learning in higher education: A bibliometric analysis with latent semantic approach. *Computers in Human Behavior*, *104*, Article 106177. https://doi.org/10.1016/j.chb.2019.106177

*Skead, N., & Offer, K. (2016). Learning law through a lens: Using visual media to support student learning and skills development in law. *Alternative Law Journal*, *41*(3), 186–190. https://doi.org/10.1177/1037969X1604100310

Smith, E.E., Kahlke, R., & Judd, T. (2020) Not just digital natives: Integrating technologies in professional education contexts. *Australasian Journal of Educational Technology*, *36*(3), 1–14. https://doi.org/10.14742/ajet.5689

*Songkram, N. (2017). Virtual smart classroom to enhance 21st century skills in learning and innovation for higher education learners. In *Proceedings of the Tenth International Conference on Mobile Computing and Ubiquitous Network* (pp. 1–4). IEEE. https://doi.org/10.23919/ICMU.2017.8330109

*Stewart-Lord, A. (2016). From education to research: A journey of utilising virtual training. *Journal of Radiotherapy in Practice*, *15*(1), 85–90. https://doi.org/10.1017/S1460396916000030

*Stokes, J. (2017). Inclusion and engagement by design: Creating a digital literacy course to inspire diverse learners in an Australian university enabling program. *International Studies in Widening Participation*, *4*(2), 65–78. https://novaojs.newcastle.edu.au/ceehe/index.php/iswp/article/view/85

Sung, Y.-T., Chang, K.-E., & Liu, T.-C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education*, *94*, 252–275. https://doi.org/10.1016/j.compedu.2015.11.008

Sung, Y.-T., Lee, H.-Y., Yang, J.-M., & Chang, K.-E. (2019). The quality of experimental designs in mobile learning research: A systemic review and self-improvement tool. *Educational Research Review*, *28*, Article 100279. https://doi.org/10.1016/j.edurev.2019.05.001

*Swartz, E., Pearson, M., Vazquez, E. A., Striker, R., & Singelmann, L. (2019). Innovation based learning on a massive scale. In *Enhancing workforce diversity and inclusion—Proceedings of the 2019 Learning with MOOCs Conference* (pp. 90–95). IEEE. https://doi.org/10.1109/LWMOOCS47620.2019.8939635

*Teixeira, A. M., Mota, J., Do Carmo Teixeira Pinto, M., & Morgado, L. (2019). ¿Pueden los MOOC Cerrar la Brecha de Oportunidades?: La contribución del diseño pedagógico social inclusivo [Can MOOCs close the opportunity gaps? The contribution of social inclusive pedagogical design]. *Revista Fuentes*, *21*(2), 239–252. https://doi.org/10.12795/revistafuentes.2019.v21.i2.08

Thompson, K., Corrin, L., Hwang, G.-J., & Lodge, J. M. (2021). Trends in education technology in higher education. *Australasian Journal of Educational Technology*, *37*(3), 1–4. https://doi.org/10.14742/ajet.7396

*Titus, S., & Ng'ambi, D. (2014). Exploring the use of digital gaming to improve student engagement at a resource poor institution in South Africa. In C. Busch (Ed.), *Proceedings of the 8th European Conference on Games Based Learning* (Vol. 2, pp. 742–748). Academic Conferences and Publishing International Ltd.

United Nations Statistics Division. (2021). *Standard country or area codes for statistical use (M49)*. Retrieved September 28, 2021, from https://unstats.un.org/unsd/methodology/m49/

UNESCO Institute for Statistics. (2015). *International standard classification of education: Fields of education and training 2013 (ISCED-F 2013) – Detailed field descriptions.* http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-fields-of-education-and-training-2013-detailed-field-descriptions-2015-en.pdf

*Vana, K., & Silva, G. E. (2014). Evaluating the use of a simulated electronic health record and online drug reference in a case study to enhance nursing students' understanding of pharmacologic concepts and resources. *Nurse Educator*, *39*(4), 160–165. https://doi.org/10.1097/NNE.0000000000000046

*Vázquez-Cano, E. (2014). Mobile distance learning with smartphones and apps in higher education. *Educational Sciences: Theory & Practice*, *14*(4), 1505–1520.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, *27*(3), 425–78. https://doi.org/10.2307/30036540

Weller, M. (2020). *25 years of ed tech*. Athabasca University Press. https://doi.org/10.15215/aupress/9781771993050.01

*Wilks, J., Wilson, K., & Kinnane, S. (2017). Promoting engagement and success at university through strengthening the online learning experiences of Indigenous students living and studying in remote communities. In J. Frawley, S. Larkin, & J. Smith (Eds.), *Indigenous pathways, transitions and participation in higher education: From policy to practice* (pp. 211–233). Springer. https://doi.org/10.1007/978-981-10-4062-7_13

Willems, J., Farley, H., & Campbell, C. (2019). The increasing significance of digital equity in higher education. *Australasian Journal of Educational Technology*, *35*(6), 1–8. https://doi.org/10.14742/ajet.5996

*Willemse, J. J., Jooste, K., & Bozalek, V. (2019). Experiences of undergraduate nursing students on an authentic mobile learning enactment at a higher education institution in South Africa. *Nurse Education Today*, 7469–7475. https://doi.org/10.1016/j.nedt.2018.11.021

Zawacki-Richter, O., & Latchem, C. (2018). Exploring four decades of research in Computers & Education. *Computers & Education*, *122*, 136–152. https://doi.org/10.1016/j.compedu.2018.04.001

*Zhang, L. (2019). Illustration design teaching mode based on virtual wall painting technology. *International Journal of Emerging Technologies in Learning*, *14*(3), 190–200. https://doi.org/10.3991/ijet.v14i03.10108

Corresponding author: Derek L. Choi-Lundberg, derek.choilundberg@utas.edu.au

Please cite as: Choi-Lundberg, D. L., Butler-Henderson, K., Harman, K., & Crawford, J. (2023). A systematic review of digital innovations in technology-enhanced learning designs in higher education, *Australasian Journal of Educational Technology*, *39*(3), 133-162. https://doi.org/10.14742/ajet.7615

Appendix A. Search strings for each database

Database	Search string
EBSCO	AB (Digital OR electronic OR elearning OR e-learning OR online OR blended OR environment OR ecology OR mobile OR virtual OR “mixed reality” OR “augmented reality”) AND AB (Design OR development) AND AB (Teaching OR learning OR pedagogy OR curriculum) AND AB (“Higher education” OR tertiary OR university OR college) AND AB (Innovate OR innovation OR innovating)
Informit	[Abstract: digital OR Abstract: electronic OR Abstract: elearning OR Abstract: e-learning OR Abstract: online OR Abstract: blended OR Abstract: environment OR Abstract: ecology OR Abstract: mobile OR Abstract: virtual OR Abstract: 'mixed reality' OR Abstract: 'augmented reality'] AND [Abstract: design OR Abstract: development] AND [Abstract: teaching OR Abstract: learning OR Abstract: pedagogy OR Abstract: curriculum] AND [Abstract: ‘higher education’ OR Abstract: tertiary OR Abstract: university OR Abstract: college] AND [Abstract: innovate OR Abstract: innovation OR Abstract: innovating]
Ovid	((Digital or electronic or elearning or e-learning or online or blended or environment or ecology or mobile or virtual or mixed reality or augmented reality) and (Design or development) and (Teaching or learning or pedagogy or curriculum) and (Higher education or tertiary or university or college) and (Innovate or innovation or innovating)).ab.
ProQuest	ab(Digital OR electronic OR elearning OR e-learning OR online OR blended OR environment OR ecology OR mobile OR virtual OR “mixed reality” OR “augmented reality”) AND ab(Design OR development) AND ab(Teaching OR learning OR pedagogy OR curriculum) AND ab(“Higher education” OR tertiary OR university OR college) AND ab(Innovate OR innovation OR innovating)
Scopus	(ABS (digital OR electronic OR elearning OR e-learning OR online OR blended OR environment OR ecology OR mobile OR virtual OR "mixed reality" OR "augmented reality") AND ABS (design OR development) AND ABS (teaching OR learning OR pedagogy OR curriculum) AND ABS ("Higher education" OR tertiary OR university OR college) AND ABS (innovate OR innovation OR innovating))
Web of Science	Digital OR electronic OR elearning OR e-learning OR online OR blended OR environment OR ecology OR mobile OR virtual OR “mixed reality” OR “augmented reality” (Abstract) and Design OR development (Abstract) and Teaching OR learning OR pedagogy OR curriculum (Abstract) and “Higher education” OR tertiary OR university OR college (Abstract) and Innovate OR innovation OR innovating (Abstract)

Appendix B. Selected summary information for the 130 publications included in the systematic review

The Appendix B Excel file contains selected summary information for the 130 publications included in the systematic review, including (a) publication number, (b) citation, (c) reference, (d) year of publication, (e) publication type, (f) countries, (g) geographic regions, (h) disciplines or subjects, (i) fields of education, (j) participant type, (k) number of participants, (l) format of course, (m) digital innovations or technologies and learning designs, (n) categories of digital innovations, (o) Kirkpatrick levels, (p) Cook and Ellaway categories, (q) research type, (r) quantitative research subtype, and (s) cited in main text (yes/no).

The file (in .xlsx and .csv formats) may be obtained at https://doi.org/10.25959/dxqt-p586.

Appendix C. Indicators of levels and quality of evidence and evaluation, and additional characteristics of included publications

Quality assessment

One of us rated all publications with MMAT or QATTL. For the empirical publications, 62 were rated low (19 conference papers and 43 journal articles), 44 medium (1 book chapter, 3 conference papers and 40 journal articles) and 19 high-quality (3 conference papers and 16 journal articles) with MMAT. Comparing the 25 conference papers and 99 journal articles rated with MMAT (only one of two book chapters was rated with MMAT), the rating of conference papers (mean 20%, standard deviation 26%, mean rank = 40) was significantly lower than journal articles (mean 38%, standard deviation 25%, mean rank = 68), Mann-Whitney U test $z = -3.503$, $p < 0.001$). Four reviews were rated medium and one high quality with QATTL. Another author or research assistant also rated the publications. Correlation (Pearson's r) between first and second raters' scores was 0.86.

Kirkpatrick's (1959) levels of evidence as adapted for HE contexts (Praslova, 2010) (Research sub-question 4)

Level 0 (engagement) data were presented in 27 publications, including percentage of students accessing or number of hits for e-resources and websites, number of plays of games, completion rates of MOOCs and individual e-resources, and number of blog, microblog or discussion board posts. Occasionally, this data was correlated with learning outcomes, and frequently presented along with reaction (Level 1) data ($n = 24$) and/or evidence of learning (Level 2) data ($n = 8$).

Most publications ($n = 113$) reported Kirkpatrick Level 1 (reaction) evidence from participants, such as opinions of the innovation's quality, useability and usefulness for gaining understanding, developing skills, changing attitudes and perspectives, making social connections with classmates, or giving or receiving feedback. Participants' self-reported levels of motivation, involvement, interest or enjoyment, self-assessment of their learning, or suggestions for improvements were also presented. These data were collected through various means including surveys with closed and open-response items, interviews, focus groups, observations during learning activities, university-run course evaluations, or analysis of reflective journals or posts on the LMS, blogs or social media.

Kirkpatrick Level 2 evidence (measured learning outcomes) was presented in 44 publications. Evidence included students meeting professional course accreditation outcomes, course retention and pass rates, course grades, examination or quiz scores, project or assignment assessments, or tutor opinion of student performance based on observation in learning activities. Learning outcomes were often compared to historical control cohorts without the innovation or occasionally to a contemporaneous control group with randomisation at the classroom or individual level, or a longitudinal comparison pre- and post-intervention, including pretest, post-test and/or delayed post-test.

Kirkpatrick Level 3 evidence (behaviour) was presented in two publications. Students in a postgraduate educational leadership course, who were current teachers or school leaders, implemented their learning in their school contexts through leading school improvements (James et al., 2016). Similarly, students in a postgraduate course in applied learning implemented technologies in their teaching practice and acquired new leadership roles or jobs (Donnelly, 2019).

Kirkpatrick Level 4 evidence (results) was presented in five publications with authentic, experiential learning contexts. Students produced digital media projects for external partners (Stokes, 2017); worked with community groups and a museum to develop social media sites, websites, mobile apps and associated marketing materials for sustainable products and services (Franqueira et al., 2017); and designed working prototypes for partner companies, one of which resulted in a patented product (De Ville et al., 2016). Electrical and computer engineering students addressed authentic problems in partnership with faculty, resulting in grants, patents, and companies founded (Swartz et al., 2019). Boone et al. (2018)

described the Michigan sustainability cases, multimedia web-hosted case studies which enabled experiential learning and collaboration with local communities.

Cook and Ellaway (2015) evaluation framework (Research sub-question 5)

Nearly all publications (*n* = 123) provided a needs analysis and environmental scan, identifying teaching and learning issues in their context and a review of relevant literature related to existing digital technologies and in many cases the needs of organisations, professions or the HE sector. Most publications (*n* = 114) provided information on processes (e.g., project management, staff development or technical support), goals and/or technology platforms (existing, or describing their development). Use of the envisioned digital innovation in learning designs frequently referenced student-centred learning, scaffolding, problem solving, social constructivism or development of 21st century skills (transversal or generic graduate attributes) including creativity, communication, collaboration, critical thinking and local to global citizenship. Many publications (*n* = 24) reported a pilot study only or included pilot testing and subsequent improvements. Most publications (*n* = 115) provided information on implementation of digital innovations and learning designs. However, in many cases the information provided was superficial. Assessment of participant experiences and learning outcomes are summarised above, as they align with Kirkpatrick Level 1 and Levels 2–4 respectively.

Issues of cost and/or sustainability of digital innovations were discussed in 46 publications. For example, MOOCs provide free access but may be resource-intensive for institutions and staff who develop and run them; connectivist MOOCs can partially address this issue with crowd-sourcing materials and feedback (Chan et al., 2015). Free software, websites, applications, and open educational resources are theoretically available to all, but hardware, network access, data costs and accessibility limits access for many (James et al., 2016; Willemse et al., 2019). Inexpensive mobile instrumentation and virtual simulation can improve STEM learning opportunities in low-resource universities that cannot afford expensive physical equipment (Astatke et al., 2015, Padilha et al., 2019). Institutions should provide resources for adoption or design and development, local implementation and evaluation, ongoing use, and diffusion of technologies through the institution (Alaeddine et al., 2015; Barrette, 2015) to enable sustainable development and delivery. Teachers and students may need training to implement and use technologies effectively for learning (Cheung et al., 2018; Stokes, 2017).

Most frequently represented journals

Most frequently represented journals were *Australasian Journal of Educational Technology* (*n* = 7), *International Journal of Innovation in Science and Mathematics Education* (*n* = 4), J*ournal of University Teaching and Learning Practice* (*n* = 4), *Academic Medicine* (*n* = 3), I*nternational Journal of Educational Technology in Higher Education* (*n* = 3) and *Nurse Educator* (*n* = 3).

Participants

Participants were students only (*n* = 94 publications), staff only (*n* = 6), both students and staff (*n* = 20), staff and/or students and professionals and/or members of the public (*n* = 8), educators (*n* = 1) or no participants (*n* = 1). Participants numbers were not reported in all studies but totalled at least 15,000.