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Fourth industrial revolution—a review of applications, prospects, and challenges for artificial intelligence, robotics and blockchain in higher education

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Abstract

Much has been written about the fourth industrial revolution's (4IR) contributions to and its impact on higher education (HE). In addition, review studies have been conducted on the contributions of 4IR technologies to and on their impact on HE. Most of these studies have reviewed single 4IR technologies in isolation as attested to by the review studies cited in the current study. Against this backdrop, the current study reviewed, discussed, and synthesized the applications, prospects, and challenges of artificial intelligence (AI), robotics, and blockchain at given higher education institutions (HEIs) between 2013 and 2019 as reported by 26 selected journal articles. Employing a slightly modified version of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for searching and screening, three of the findings of this study are worth mentioning. Firstly, the dominant AI technologies for learning are chatbots, and AI holds the prospect of personalized, scalable, and affordable learning. Secondly, the applications of robotics are exploratory in nature, and have a meta-teaching and a meta-learning orientation. Thirdly, some of the applications of blockchain relate to digital grading, digital credentialing and digital certification, and to real-time contracting and time stamping of learning. The implications of this review are that the three sets of technologies reviewed, have a lot applications for HE, barring the challenges that have been outlined.

Keywords: Fourth industrial revolution, Higher education, Artificial intelligence, Robotics, Blockchain

Introduction

Since the mantra of the 21st century skills, no phrase has gained as much traction and hype as the fourth industrial revolution (4IR). With its roots embedded in the industry sector, 4IR seems to be permeating different sectors of society of which education, and especially higher education, is but one. Besides the code 4IR, the fourth industrial revolution goes by other codes such as IR 4.0 or 4th IR (Reaves, 2019; Sani, 2019; Shahroom & Hussin, 2018), Industrie 4.0 (Thoben et al., 2017) and Industry 4.0 (Schwab, 2016). Its cognate codes have seen other permutations in some of the sectors in which it has made its inroad. Two such permutations in the education sector are Education 4.0 (Bonfield et al., 2020; Chaka, 2022; dos S. Silva et al., 2020; Keser & Semerci, 2019; Marcial, 2020; Salmon, 2020), Higher Education 4.0 (Adnan et al., 2021; Chea & Huan, 2019; Goh & Abdul-Wahab, 2020; Sharma, 2019), and University 4.0 (Giesenbauer & Müller-Christ, 2020; Gueye & Exposito, 2020).

Briefly stated, 4IR refers to the fourth epoch of industrial revolution. Its preceding epochs are the first industrial revolution (1IR), the second industrial revolution (2IR), and the third industrial revolution (3IR). There are other permutations of these industrial revolutions, such as Industrial Revolution 1.0, Industrial Revolution 2.0, and Industrial Revolution 3.0, including Industrial revolution 4.0 for 4IR (Chaka, 2022; Chea & Huan, 2019; Keser & Semerci, 2019; Sharma, 2019). However, the current paper prefers using 4IR over all the other monikers for the fourth wave of the industrial revolution. In this context, 1IR was about mechanization and the steam engine; 2IR entailed mass production and the use of electric power; and 3IR involved automation and computerization (Chea & Huan, 2019; Salmon, 2019; Sharma, 2019).

For its part, 4IR, notwithstanding some of its vague characterizations, refers to an era in which the physical, the virtual, and the biological lives get fused within cyber-physical systems through connected automated machines, workpieces, smart networks, sensors, and other digital technologies that communicate and interact with one another, and with human beings, remotely and in real-time (Butt et al., 2020; Chaka, 2020; Penprase, 2018; Salmon, 2019). Some of the technologies associated with it are: autonomous robots; artificial intelligence (AI); blockchain; virtual reality (VR); augmented reality (AR); the Internet of Things (IoT) or Industrial Internet of Things (IIoT); cloud computing; quantum computing; big data; smart sensors; simulation; additive manufacturing; 3D printing; holograms; and drones (Bongomin et al., 2020; Butt et al., 2020; Chaka, 2021, 2022; Keser & Semerci, 2019; Reaves, 2019; Salomon, 2019; Sharma, 2019). Generally, the year 2011 is regarded as 4IR’s launch year (Schwab, 2016).

Of the 4IR technologies mentioned above, AI, robots, VR, AR, and blockchain have been studied in relation to their educational value. In some instances, review studies on their educational value have been conducted as well. However, mostly, such studies tend to focus on these technologies individually. Examples of such studies are Zawacki-Richter et al. (2019) (AI); Belpaeme et al. (2018) and Mubin et al. (2013) (robots); Alammary et al. (2019) (blockchain); and Peixoto et al. (2021) (VR). Against this brief backdrop, the purpose of the current review is to review the applications, prospects, and challenges of artificial intelligence (AI), robotics, and blockchain at given higher education institutions (HEIs) between 2013 and 2019 as reported by 26 reviewed journal articles. In this regard, the main focus is on foregrounding and synthesizing the applications, prospects, and challenges of these three 4IR technologies at the given HEIs. The implications of these three key areas are provided within a broader discussion and synthesis of the findings, and duly framed within the higher education (HE) ecosystem.

Artificial intelligence, robotics and blockchain in higher education: A brief overview

Artificial intelligence (AI), as is currently conceptualized, has its roots in the 1950s and is often credited to John McCarthy. Broadly, as a branch of computer science, AI entails the use of programmed machines that simulate human intelligence, or the use of software programmes capable of using language, forming concepts and abstractions, solving problems, and executing cognitive tasks reserved for a human brain. It has its alter egos or its cognate sub-fields such as machine learning and deep learning. There is strong and weak (or general and narrow) AI. The former is context-agnostic and has the capability or consciousness to function in more than one context, whereas the latter is domain-specific and context-constrained (Zawacki-Richter et al., 2019). The inroad of AI into education has resulted in a scholarly area known as AI in education (AIED). This area deals mainly with the development and evaluation of, and research into artificial intelligent systems that are intended to improve teaching and learning. Two examples of such systems are intelligent tutoring systems and intelligent virtual reality (Holmes, 2019; Zawacki-Richter et al., 2019). In this context, AI is one of the flagship technologies behind 4IR.

Robots are classified into industrial robots, service robots, social robots, and educational robots, with robotics as an area being applied in multiple fields of study like informatics, electrical engineering, mechanical engineering (Ruzzenente et al., 2012), and language learning (Mubin et al., 2013). Educational robots, as a subset of educational technology, have been used for various purposes, two of which are improving academic performance and facilitating learning. A sub-class of robots that display human-like attributes are called humanoid robots, and have been used in education for some time (Mubin et al., 2013). Most educational robots have specific personal names and, in certain instances, there are robotics kits employed in education, one of which is LEGO Mindstorms (see Ruzzenente et al., 2012), which has been applied extensively in the higher education sector. In addition, social robots have been employed in education in which instance there is a human-robot interaction (see Belpaeme et al., 2018) characterizing some of the applications of social robots as opposed to stand-alone, autonomous robots.

Credited to Satoshi Nakamoto, blockchain is the backbone technology of the cryptocurrency, Bitcoin, which functions as immutable and verifiable distributed ledgers. Its operative words are transparency, decentralization, trustworthiness, and immutability, in terms of transactions carried out in a chain of blocks. One of the cardinal characteristics of blockchain is the consensus that constitutive nodes in a distributed blockchain network collectively have. Three types of algorithms through which to establish consensus are: a Point-of-Work (PoW) distributed consensus algorithm; a proof-of-stake consensus algorithm leveraging smart contract functionality; and a proof-of-zero-knowledge distributed consensus algorithm. The first consensus is utilized by the Bitcoin blockchain, while the last two consensus algorithms are employed by Ethereum and Zerocash (Zcash), respectively. Three stages of the blockchain development are distinguishable, and bear some parallel to Web 1.0, Web 2.0 and Web 3.0. These are Blockchain 1.0, Blockchain 2.0, and Blockchain 3.0. Blockchain 1.0 represents the use of cryptocurrencies mainly as a peer-to-peer cash transaction system. Blockchain 2.0 goes beyond cash transactions and incorporates transactions of other assets such as loans, bonds, stocks, smart property, and smart contracts. Finally, Blockchain 3.0 involves extending blockchain applications to the different spheres of life like education, science, health, art, and culture (Chen et al., 2018). Like AI and robotics, blockchain is one of the enabling technologies of 4IR.

Purpose of the review and research questions

The purpose of this review study was to review the applications, prospects, and challenges of artificial intelligence, robotics and blockchain at given higher education institutions (HEIs) between 2013 and 2019 as reported by 26 reviewed journal articles. Most reviews conducted on 4IR technologies have done so by focusing on individual technologies (e.g., artificial intelligence, robotics, Internet of Things, and virtual reality) (Alammary et al., 2019; He & Liang, 2019; Spolaôr & Benitti, 2017; Zawacki-Richter et al., 2019). Therefore, it is the contention of this paper that few review studies, if any, have been conducted on any two sets of 4IR technologies simultaneously. Moreover, the paper is of the view that few review studies, if any, have been conducted on the applications, prospects, and challenges of blockchain at HEIs. In this context, firstly, applications as a term refers to the various ways in which these sets of technologies are applied at HEIs. Secondly, prospects as a concept relates to the current and future opportunities and the potential these technologies have for HEIs. It is a concept that is futuristic in its orientation and that transcends the current applications of these technologies. Thirdly, challenges are about the problems, drawbacks or hindrances attendant to the use of these three sets of technologies (cf. Bucea-Manea-Ţoniş et al., 2022; Sousa et al., 2022). In addition, these three terms have been used in this paper as characteristics or variables that each review study has.

Thus, it is necessary to conduct a review study into the applications, prospects, and challenges related to these sets of 4IR technologies in the higher education sector. This is especially so given the ongoing COVID-19 pandemic as HEIs require some of the 4IR technologies to help them continue with their academic business. Thus, the current study is intended to fill this gap. Against this background, this paper had the following research questions (RQs):

- RQ1: What are the applications of artificial intelligence, robotics and blockchain at given HEIs between 2013 and 2019 as reported by selected journal articles?
- RQ2: What are the prospects and challenges of applying artificial intelligence, robotics and blockchain at given higher education institutions (HEIs) between 2013 and 2019 as reported by selected journal articles?

Method

One of the purposes of a review is to survey and review specific aspects of a field of study with a view to answering specific questions. Often such a review is informed by explicit review guidelines. Some of these guidelines include the following: purpose of review; research questions; search strategy; inclusion/exclusion criteria; study selection; inter-coder reliability; coding; and data extraction and analysis (see, for example, Spolaôr & Benitti, 2017; Zawacki-Richter et al., 2019).

Search strategy, inclusion/exclusion criteria and study selection

The search strategy was conducted online from May 2019 to November 2019, and began by identifying online databases and academic social networking sites. Google search engine and six online databases (Google Scholar, Semantic Scholar, Education Resources Information Center (ERIC), ScienceDirect, SpringerLink, and Scopus), and two online academic social networks (ResearchGate and Academia.edu), were identified (see Figure 1). Search strings were arranged into super- and sub-classes in line with the three key areas on which the review study focused: artificial intelligence, robotics, and blockchain. Examples of search strings used were as follows:

- Search string: ((artificial intelligence sub-string) AND (applications sub-string) AND (prospects sub-string) AND (challenges sub-string) AND (higher education sub-string))
- Artificial intelligence sub-string: AI OR artificial neural intelligence OR neural network OR intelligent learning OR intelligent tutoring OR intelligent machine learning OR intelligent agent OR intelligent chabot OR automated tutor
- Applications sub-string: use OR usage OR uses OR impact OR educational use OR educational usage OR educational uses OR educational impact

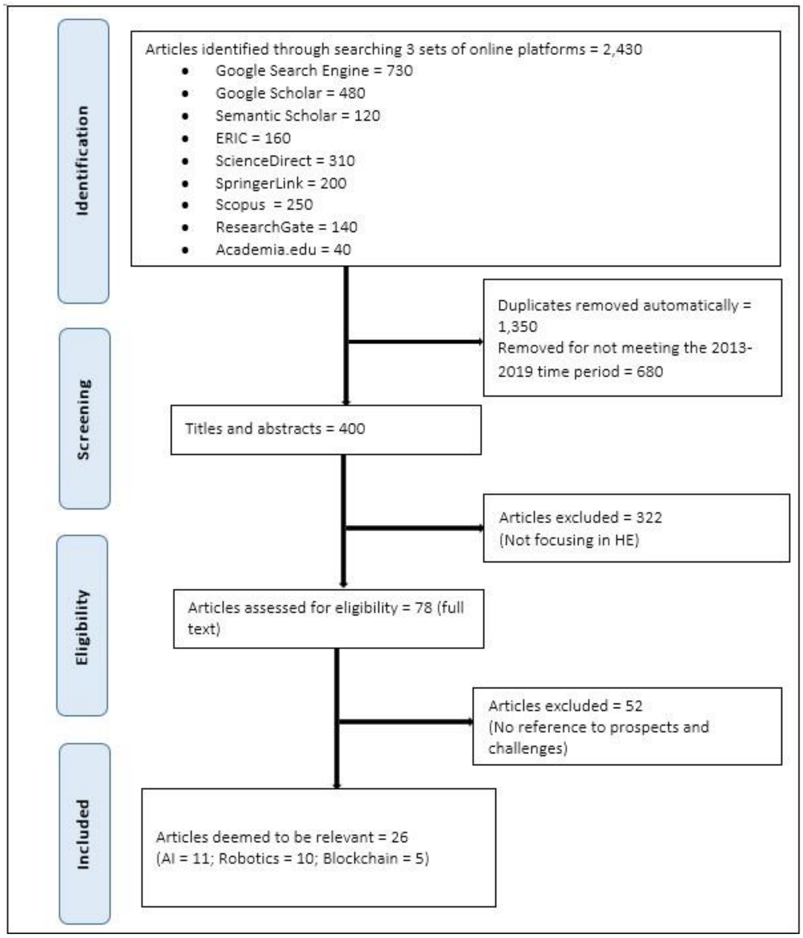

Fig. 1 Journal articles search and screening flowchart

The foregoing search strings and their attendant sub-strings were also applied to robotics and blockchain. These search strings and their related sub-strings were employed to search for peer-reviewed journal articles on the three sets of online search platforms mentioned above. The inclusion/exclusion criteria (eligibility criteria) used were as reflected in Table 1.

Table 1 Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Time period	Articles published between 2013 and 2019	Articles not published between 2013 and 2019
Types of articles	Articles published in peer-reviewed journals	Articles not published in peer-reviewed journals
Content and focus of articles	Articles focusing on applications, prospects, and challenges of AI, robotics, and blockchain in HE	Articles not focusing on applications, prospects, and challenges of AI, robotics, and blockchain in HE
Language of publication	Articles published in English	Articles not published in English

The current review followed the guidelines based on a modified version of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (see Brunton & Thomas, 2012; Moher et al., 2009; also see Figure 1). It did so by employing a four-stage process that involved searching for, identifying, screening, and selecting relevant articles. The first stage entailed searching for and identifying articles by querying search string combinations into the search platform and the online bibliographic databases mentioned earlier. In all, 2,430 articles were returned during this stage. This stage was followed by the second one in which all the 2,430 returned articles were screened. During the screening process, 1,350 duplicate articles were eliminated and 680 articles were excluded as they fell outside the 2013-2019 time period. This resulted in 400 articles being retained, whose titles and abstracts were reviewed during the third stage. After conducting this process, 322 articles were excluded as they did focus on the HE sector. The remaining 78 articles, as full texts, had their contents reviewed and assessed for relevance during the fourth stage. During this stage, 52 articles were eliminated because they did not make any reference to prospects and challenges related to either AI, robotics or blockchain. As a result, 26 articles were regarded as relevant, and were included as a major data source for this study.

Data extraction, coding, and inter-coder reliability

Data sets were extracted from the 26 journal articles based on the three key focus areas (applications, prospects, and challenges) related to AI, robotics, and blockchain in HEIs. These data sets were represented in three separate Microsoft (MS) Word files in line with the three 4IR technologies. Codes included study type; study/application purpose; study site; educational level; technologies used; summary of findings; summary of conclusions; prospects; challenges; and recommendations. In other words, all of these article features were treated as variables for a coding scheme. These ten codes were treated as article characteristics that informed the study's coding scheme (see Tables 2, 3 and 4). Most importantly, applications, prospects, and challenges were conceptualized as explained earlier on. They were, then, coded in line with this conceptualization and in keeping with how each article referred to or mentioned them. For example most applications for AI, robotics or blockchain were in the form of the purposes that studies served.

Two coders, coders A and B, were involved in identifying, screening, and coding articles. They also assessed the suitability of the 26 articles which were selected for synthesis. An inter-coder reliability was determined by employing Cohen's kappa (κ) (Cohen, 1960). The latter is a co-efficient used to determine the degree of consistency among coders based on kappa coding values. For instance, kappa values are weighted as follows: .75 to 1.00 = excellent; .60 to .75 = good; and .40 to .60 = fair (see Chaka, 2020, 2021; McAlister et al., 2017; O'Connor & Joffe, 2020; Zawacki-Richter et al., 2019). The degree of consistency for including or excluding articles between coders A and B was $\kappa = .77$. This value is considered as excellent according to calibrated κ coding values. Disagreements between the two coders were resolved through consensus.

Data analysis

Data sets extracted from the reviewed articles in the form of ten characteristics were analyzed as themes using quantitative content analysis and qualitative content analysis (Fass & Turner, 2015; Vaismoradi & Snelgrove, 2019). First, quantitative content analysis involved establishing and aggregating the ten article characteristics for each of the three sets of 4IR technologies under review in this study: AI, robotics, and blockchain. Second, qualitative content analysis entailed extracting themes from the ten article characteristics, and iteratively comparing and synthesizing these themes for each of the three sets of 4IR technologies.

Findings

Artificial intelligence

Eleven articles were reviewed. Of these articles, nine mentioned their types of studies, while two did not specify their study types (see Table 2). The study types specified are: two quasi-experimental studies; an overview study; an exploratory mixed-methods study; a pilot study; a multiple descriptive case study; an implementation study; a quantitative single-case study; and a prospective comparative study. All articles state their AI usage purposes (study purposes). These usage purposes involve, on the one hand, measuring the effectiveness of chatbot systems on students' learning outcome and memory retention (Abbasi & Kazi, 2014) and examining the effects of conversing with a chatbot on critical thinking, and satisfaction with online discussion forums in an English as a foreign language (EFL) environment (Goda et al., 2014). On the other hand, they entail investigating students' participation in online courses, their synchronous interaction with a conversational virtual agent, their relationships with student performance, the interaction factor identification (Song et al., 2019), and improving the acquisition of skills by medical interns using a new intervention programme (Yang & Shulruf, 2019).

All of the mentioned studies, except for the one whose research site is not specified, took place at universities, and their participants were either undergraduate or graduate students (see Table 2). Some of the university courses to which AI was applied include the following: information technology; English as a foreign language (EFL); psychotherapy; biomechatronics; health sciences; maths sciences; computer science; engineering; and instructional technology.

Table 2 Themes related to AI as extracted from the 11 journal articles

Author(s) & Year	Study Type	Study/Application Purpose	Study Site	Educational Level	AI Technology	Sum. of Findings	Sum. of Conclusions	Prospects	Challenges	Recommendations
Abbasi & Kazi (2014)	Not mentioned	Measure effectiveness of chatbot systems on students' learning outcome and memory retention	Sindh Agriculture University Tandojam	Second-year undergraduate IT students (n = 72)	OOPLChatbot and Google	Learning through a chatbot improved students' memory retention and learning outcomes	A chatbot system is an efficient system for measuring and improving learning by students compared to Google	The School of computing at the University of Leeds' School of Computing uses FAQChat	Not mentioned	Not provided
Goda et al. (2014)	Quasi-experimental	Examine effects of conversing with a chatbot on critical thinking, and satisfaction with online discussion forums in EFL between 2 groups	A Japanese university	Undergrad EFL students (n = 130)	Eliza - an AI-powered chatbot	A chatbot's pre-discussion activities affected students' critical thinking differently	No significant differences between experimental and control groups in students' critical thinking and satisfaction	Deploying a chatbot might have a significant impact on students' cognition, affection, and behaviour in online discussion forum	Current chatbots still primitive	Not provided
Popenici & Kerr (2017)	Not mentioned	Offer bespoke content, guidance, help, and supervision to students & administrative feedback	Oxford, Harvard, MIT & George Tech	University level (psychotherapy, biomechatronics, health sciences, technology, and computer science)	IBM's Watson, chatbots & MOOCs	Teachers' roles and pedagogies in the HE sector need re-envisioning in the light of AI	Not provided	Possibility of personalised, scalable, and affordable learning	Casualisation and outsourcing of teaching	Further research needed

Duzhin & Gustafsson (2018)	Quasi-experimental	Apply a machine learning algorithm that uses non-experimental data on students' previous scores harvested by a university as input	Not mentioned	Undergraduate university maths sciences	A machine learning algorithm that is capable of providing definitive human-interpretable models without assuming any symbolic regression	Clickers as a teaching strategy were more effective than traditional handwritten homework, but online homework backed by instant feedback showed to be more effective than clickers	Study claims to be one of the first to have investigated the effectiveness of clickers in undergraduate mathematics teaching	Potential for machine learning-based analysis of non-experimental data	Not mentioned	Not mentioned
Khare et al. (2018)	Overview	Incorporate AI into classrooms for monitoring, advising, tutoring, grading and assessing	Multiple sites (e.g., Deakin University & Georgia Tech)	Computer science	Chatbots (e.g., IBM Watson supported chatbots, intelligent tutors or intelligent teaching assistants, and intelligent tutoring systems), automated essay graders & AdmitHub	Not provided	Synergistic integration of AI-aided technology and human tutors for student support	(a) Possibility of AI-driven graders reducing the time human graders spend grading student work (b) The potential for one-on-one tutor engagement	No evidence of the application of cognitive tutors at university level yet	No privileging of tech-solutionism to human solutions, or vice versa
Krassmann et al. (2018)	Exploratory mixed methods	Explore students' mood states as deduced from a chat log analysis of interactions between students and a conversational agent	A Brazilian public university	Distance education post-graduate course students	A web-based conversational agent called Mediator of Education in Technology of Information and Socializer (CA METIS)	There was an association between satisfaction, interest and utility perceived by students with their mood states as detected by the chat log analysis	Students under-utilised the CA	CAs serve as support tools likely to reduce social isolation in distance education	CAs cannot express all human emotions	Not provided

Sandoval (2018)	Pilot study	Create and implement a chatbot (prototype) that answers frequently asked questions (FAQs) related to a graduate online course	Middle Georgia State University	Online graduate course level students	Snatchbot	The chatbot, which was embedded in the graduate online course's learning management system, performed as expected	The chatbot still needs to be programmed with more information related to the graduate online course	Chatbots are likely to change the way students learn and search for information in HEIs	Chatbots have to be fed with more relevant FAQs, and ach online course requires its own bespoke chatbot	Not provided
Stachowicz-Stanusch & Amann (2018)	A multiple descriptive case study	Analyse forms of frequently asked (FAQs) and chatbots' responses to these FAQs	AGH University of Science and Technology, University of Economics in Katowice	Engineering & maths undergrad students	AI-powered chatbots, Klaudia & Wincent	Both Klaudia & Wincent were able to respond to users' questions about specialised knowledge and to users' FAQs	Polish universities use AI-powered chatbots in their promotions and in their educational offerings	The two chatbots demonstrate the role chatbots can play as virtual learning assistants in HE	Conversations involving sustained and meaningful near-human discussions not yet possible with chatbots	A need for cooperation between AI researchers and humanities and social sciences researchers when designing and creating AI-powered educational tools
Thakkar et al. (2018)	Implementation study	Employ an AI chatbot (Erasmus) as a one-stop shop to respond to queries about the college information	Sanghvi College of Engineering at the University of Mumbai	Not mentioned	An AI-powered chatbot, Erasmus	Erasmus helps Sanghvi College of Engineering attend to user queries instantly, seamlessly and virtually	Not provided	Users can query any information related to the college via the system	Not provided	Not provided
Song et al. (2019)	A quantitative single-case study	Investigate students' participation in online courses, their synchronous interaction with a conversational virtual agent, their relationships with student performance, and the interaction factor identification	A mid-sized university in the southern U.S.A.	Four instructional technology graduate level courses (n= 56 students)	A conversational virtual agent	A positive relationship between students' participation/interaction in online courses and their learning performance	The study offered how student behaviour indicators in online course are related to each other	Not provided	Conversational virtual agents cannot yet detect whether or not students engage in these cognitive tasks	Not provided

Yang & Shulruf (2019)	Prospective comparative study	Improve the acquisition of skills by medical interns using a new intervention programme	Taipei Veterans General Hospital & National Yang-Ming University's Department of Medicine	Undergrad level medical interns	Artificial skin connected to an AI recording and analysis system for suture/ligature training	The expert-led+AI group had the highest end-of-surgical block objective structured clinical examination (OSCE) performance and self-assessed confidence in suturing/ ligature skills	Raising the frequency of practice with the AI system enhanced medical interns' performance and confidence in suturing/ ligature skills	Not provided	Not provided	Suturing tutoring needs to be applied in parallel with real patient practice to improve medical interns' confidence in suturing skills

There are different AI technologies that were applied. These range from chatbots (some of which were AI-powered, e.g., OOPLChatbot, Eliza and Erasmus) to automated graders to an artificial skin connected to an AI recording and analysis system. Ten articles have a summary of findings, while nine articles, each, have a summary of conclusions and AI prospects, respectively. Finally, seven articles mention challenges, whereas only four articles provide recommendations for further research (see Table 2).

Robotics

For this section, ten articles were reviewed. Of these ten articles, eight identify their study types, while two do not do so (see Table 3). The following are the eight study types mentioned: three survey studies; a review study; a case study; experimental study (2 in one study); a systematic review; and an exploratory study. All of these articles state their robotics usage purposes (study purposes). Two of these usage purposes are: to review the role LEGO robotics has played in college engineering education in the last 15 years (from 1998 to 2013) (Bada et al., 2013); and to evaluate the efficacy of a multi-component robot-assisted instructional package to teach three students with intellectual disabilities (ID) to write text messages such as a greeting, personal narrative, and closing (Pennington et al., 2014). The other two are: to investigate how a robotic teaching assistant can be used at a university level (Cooney & Leister, 2019); and to survey how instructors and students perceive robotics (robotics-related technology) as applied to their teaching and learning (He & Liang, 2019).

Nine of the mentioned studies, barring one whose research site is not specified, occurred at universities. Except for two studies whose participants' educational levels are not specified, seven studies had undergraduate students as their participants, while one study had graduate students as its participants (see Table 3). Among the university courses provided by some of the studies reviewed are the following: business computing students; college engineering education; educational robotics course; cognitive psychology; and engineering education.

Different robotics technologies are reported to have been applied by the ten articles. These include, on the one hand, a rescue robot, LEGO Mindstorms, a humanoid robot (NAO model H25), and BrianFarm, Parallax sumobot, and Baxter, on the other hand. Nine articles have a summary of findings, while another nine mention robotics prospects. Eight articles provide a summary of conclusions, with six articles, apiece, offering challenges and recommendations, respectively (see Table 3).

Table 3 Themes related to robotics as extracted from the 10 journal articles

Author(s) & Year	Study Type	Study/Application Purpose	Study Site	Educational Level	Robotic Technology	Sum. of Findings	Sum. of Conclusions	Prospects	Challenges	Recommendations
Bada et al. (2013)	A survey study	Develop a prototype of a robot using project-based learning approach so as to demonstrate the capability of a robot to solve real-world problems	Makerere University	Undergrad business computing students	A rescue robot powered in the Arduino prototyping platform	Students developed skills robot development, circuit design, and problem-solving for addressing real-world problems in a team work	Robotics education employing project-based learning motivates students to learn and use computer artefacts that address real-world problems	Not provided	Technical issues, personal challenges and infrastructural challenges	Not provided
Danahy et al. (2014)	Review study	Review the role LEGO robotics has played in college engineering education in the last 15 years (from 1998 to 2013)	Tufts University, University of Nevada (Reno), Arizona State University, and University of Notre Dame (Australia)	College engineering education students	LEGO Mindstorms	Not provided	LEGO Mindstorms tools enable engineering education (and non-engineering education) students to deal with questions related to motor latency, sensor accuracy, priorities and response times without much knowledge of artificial intelligence	LEGO toolkit exposes students to problem-solving, team work, and project-based learning (PBL)	Student retention is a problem	Not provided

Eguchi (2014)	A case study	Integrate LEGO Mindstorms into an undergraduate level educational robotics course (Educational Robotics as Learning Tool course)	Bloomfield College (U.S.A.)	An undergraduate level educational robotics course - liberal art college level students (n = 18 students)	LEGO Mindstorms Robotics Invention System NXT	Students discovered their learning of collaboration, cooperation, and communication skills as some of the most important learning outcomes they received from the course. Used at other HEIs such as Trinity College Dublin, University of Aarhus, Brown University, Massachusetts Institute of Technology, University of Utrecht, University of Manchester, and Tufts University	Not provided	LEGO Mindstorm helps students acquire 21st century skills (e.g., collaboration skills, communication skills, creative thinking, critical thinking & problem-solving skills)	Finding the best way to use robotics for what they are meant to teach is a challenge	Not provided

Pennington et al. (2014)	Not mentioned	Evaluate the efficacy of a multi-component robot-assisted instructional package (comprising robot, simultaneous prompting, self-graphing) to teach three students with intellectual disabilities (ID) to write text messages such as a greeting, personal narrative, and closing	University of Louisville	3 students with intellectual disability (ID), aged 19 to 21	A humanoid robot (NAO model H25, Alderbaran Robotics)	Data indicated that the package was effective in increasing correct performance for all participants.	Not provided	Robots can offer instructional components traditionally delivered by a human instructor	Even though NAO offered prompts and delivered praise, it was unable to provide specific feedback on the quality of participant responses	Not provided
Richert et al. (2016)	Two experimental case studies	1st study: Explore trainers' (behaviours) perspective within a virtual world. 2nd study: Examine the aspects of participants' collaborative problem-solving behaviour in VLEs	The University of Ulster (Germany)	1st study = 10 participants; 2nd study = not mentioned	1st study = Oculus Rift in a virtual world; 2nd study = not specified	1st study = Video data showed that the online-gaming experience and the age of participants corresponded with participants' spatial coordination within a VLE; 2nd study = preliminary findings indicate a relationship between participants' age and online-gaming experience with regard to spatial coordination within the VLE	1st study = Participants reported feeling immersed in the virtual world; 2nd study = not mentioned	Virtual simulation lends itself well to be applied to everyday engineering education at HE environments	Not mentioned	1st study = not provided; 2nd study = Further research into human-robotic collaboration is needed so as to prepare future engineers for Industry 4.0

Gabriele et al. (2017)	A survey study	Verify whether student motivation affects the learning results of arts and humanities students who engaged in different robotics concepts during an educational robotics lab	University of Calabria (Italy)	First-year cognitive psychology students (n = 136)	BrainFarm (a robotics serious game)	Students' intrinsic motivation increased	BrainFarm supported and enhanced students' cognitive abilities	Great potential for using robotics as an educational tool	Not mentioned	Experimental studies on the use of robotic serious games to support students' cognitive abilities needed
Kaya et al. (2017)	Not mentioned	Integrate engineering through robotics (LEGO Mindstorms EV3 Kit) in elementary teacher training	A south-western university in the U.S.A.	Undergraduate university level (Engineering education students)	LEGO Mindstorms EV3 Kit	It was discovered that preservice elementary teachers (PSTs) improved their nature of engineering (NOE) views after experiencing the engineering unit	Findings supported the literature that argues for explicit–reflective nature of science (NOS) instruction over implicit instructional approaches to NOS	Heightened awareness about engineering literacy arouse elementary students' interest in STEM careers	Not mentioned	Preparing PSTs to teach engineering design in elementary classrooms can serve as a first step to developing engineering literacy among elementary students

Spolaôr & Benitti (2017)	A systematic review	Systematically review relevant educational robotics experiences with theoretical support on tertiary education	N/A	Tertiary level	Virtual robot (3 articles); Lego Mindstorms (7 articles); Boe-bot (1 article); observatory (1 article); Parallax sumobot (1 article); .NET Gadgeteer (1 article); Sphero (1 article)	Robots were used mainly for: problem-solving; programming; engineering; creativity; communication; mathematical methods; digital signal processing; logical thinking; teamwork; and metacognition. Some of the learning theories reported in the review study include: project-based learning; blended learning; constructivist theory; collaborative learning; experiential learning; active construction; problem-based learning; metacognitive learning; and edutainment	Applying robotics as a teaching tool, grounded in learning theories, has the potential to support learning subjects not directly related to robotics HE	Robotics can be used in an interdisciplinary approach that involves computer science, English and Psychology to foster problem-solving and creative thinking	Experimental studies employing quantitative evaluations of educational robotics in the HE sector are still few	A need to embed activities involving robots grounded on learning theories in undergraduate curricula

Cooney & Leister (2019)	An exploratory study	Investigate how a robotic teaching assistant can be used at a university level	Halmstad University (a graduate school in Sweden)	Graduate level	A robotic teaching assistant (Baxter)	Findings indicate that using a social robot as a teaching assistant is a promising prospect	Potentially desirable capabilities for a robot teaching assistant were identified (e.g., reading, greeting, alerting, remote operation, clarification, and motion)	Personalising the capabilities of a robotic teaching assistant would be essential for improving interactions with the robotic teaching assistant	Not mentioned	Enhancing the robot's autonomous capabilities and further investigating the role of embodiment should be considered in future work
He & Liang (2019)	A survey study	Survey how instructors and students perceive robotics (robotics-related technology) as applied to their teaching and learning	Woosong University (South Korea) & Yonsei University (South Korea)?	Undergrad students (n = 204) and instructors (n = 52)	Not specified	Robotics education is of practical value for students	Robotics helps trigger curiosity in discipline-specific knowledge such as robot programming and robot construction	Robotics lends itself well as an interdisciplinary subject even though it is predominant in STEM	In many instances, instructors are not yet well-equipped to use robotics, and in most HEIs, curricula are not yet aligned to accommodate the use of robotics alongside human instructors	A need to explore the effects of the applications of robotics in HE

Blockchain

For this section, five articles were reviewed. Two of these articles are systematic reviews, while the other three do not specify their study types (see Table 4). All of them state their blockchain usage purposes (study purposes). Two of these usage purposes are: to support academic degree management and summative assessment for learning outcome (Chen et al., 2018); and to explore the application of blockchain in chemistry education students' data management (Ezeudu et al., 2018).

All these studies focus on university sites. Three of these university sites are the Massachusetts Institute of Technology (MIT) Media Lab, the University of Nicosia, and the University of Nigeria. Only one study specifies the participants and the university course for which its blockchain application was intended, whereas the other four do not. Some of the blockchain-based technologies used by the mentioned universities are Ethereum, OpenBlockChain, and Blockcerts. One study provides a summary of findings, with four studies offering a summary of conclusions (see Table 4). One instance of the latter is that the use of blockchain technology in education is still in its infancy, and is only limited to certain HEIs (Alammary et al., 2019). All the five studies offer blockchain prospects in the HE sector, one of which is real-time contracts and real-time credentialing (Chen et al., 2018). Lastly, four studies state blockchain challenges, with three studies providing recommendations about the applications of blockchain in HE settings. One of the challenges flagged is the fact that blockchain is not yet able to assess student essays and classroom presentations (Chen et al., 2018), while one of the recommendations offered is that more case studies are needed about the applications of blockchain in HE settings (Jirgensons & Kapenieks, 2018).

Below is the discussion and synthesis of the findings of the three areas as presented in the preceding sections.

Discussion and synthesis of findings

AI: Applications, prospects, and challenges in higher education

As mentioned in the preceding section, all of the eleven reviewed articles explicitly state the usage applications which AI technologies had at HEIs mentioned by them. In fact, seven of these articles state more than one AI application, with two of them mentioning six AI applications. In addition to AI applications depicted in Table 2, other AI applications stated by the reviewed articles include the following:

- developing a machine learning algorithm that recognizes students' prior knowledge (Duzhin & Gustafsson, 2018)

Table 4 Themes related to blockchain as culled from the 5 journal articles

Author(s) & Year	Study Type	Study/Application Purpose	Study Site	Educational Level	Blockchain Technology	Sum. of Findings	Sum. of Conclusions	Prospects	Challenges	Recommendations
Tapscott & Tapscott (2017	A systematic review	The MIT Media Lab issues grades, credentials and digital certificates through blockchain	The MIT Media Lab	Science classrooms	Ethereum-based blockchain	Not mentioned	By means of learning is earning approach blockchain technology can foster students' learning motivation	(a) Keep identity and student records - Blockchain can be programmed to digitally record and store almost everything by ensuring validity and saving time (b) New pedagogy - Blockchain-powered learning to free up faculty's and students' time and intellectual capital. Consensus Systems (ConsenSys), which is Ethereum-based, manages science classrooms through holacracy (c) Cost-cutting (reducing student debt) - Smart wallet for higher education as one of the future means for paying for student debt (d) Meta-university - Blockchain can help HEIs disaggregate into networks and ecosystems, not ivory towers that they currently are	Not mentioned	Blockchain-powered learning likely to free up faculty's and students' time and intellectual capital

Chen et al. (2018)	Not mentioned	Explore how blockchain technology can be used to solve some education problems; support academic degree management and summative assessment for learning outcomes; capture information about research experience, skills, online learning experience, and individual research interests	University of Nicosia uses blockchain technology to manage students' certificates obtained from MOOC platforms; MIT and the Learning Machine company designed a digital badge for online learning based on blockchain technology; Holberton School uses blockchain technology to store degrees (e.g., learning behaviour in class, micro academic project experience, and macro educational background)	N/A	Blockchain	Not mentioned	Not mentioned	(a) Real-time contracts and real-time awards through the smart card powered by Ethereum facilitating contract negotiation (b) Can mitigate free-riding associated with collaborative learning (c) Can help students, supervisors and academic advisors plan and monitor students' academic programmes through the smart contract	(a) Blockchain-aided learning not amenable to human evaluation (b) Blockchain not able to assess student essays and classroom presentations	Not provided

Ezeudu et al. (2018)	Not mentioned	Explore the application of blockchain in chemistry education students' data management	University of Nigeria	Undergrad chemistry education students	Blockchain	Not mentioned	There is a need to integrate blockchain technology into chemistry education students' data management	Support academic degree management and summative assessment for learning outcomes; Issuance of certificates and smart contracts; assessment of students' learning accomplishments; touted for immutability, efficiency, reliability, security, and trust; contributes to reducing fraudulent degrees; ability to track student's learning progress and skills acquisition; provides autonomous time stamping	The blockchain's immutability does not enable a modification of educational records for legitimate purposes	Not provided

Jirgensons & Kapenieks (2018)	Not mentioned	(a)Knowledge Media Institute's (KMI) OpenBlockChain issues students' micro-credentials documented by smart contracts (b) MIT Media Lab has a stand-alone blockchain education credentialing system that employs Blockcerts for issuing electronic certificates of accomplishment (c) The University of Nicosia (Greece) offers full blockchain credentials, including certificates and diplomas	KMI at the Open University (UK) MIT's Media Lab The University of Nicosia (Greece)	Not mentioned	OpenBlockChain Blockcerts	Not provided	Except for Estonia, blockchain is still an experimental technology in many places	(a) Different HEIs can work together to blockchain their micro-credentials. NB: KMI already collaborates with other HEIs (e.g., the University of Southampton and the University of Texas); the University of Nicosia (Greece) is part of MIT's Blockcerts consortium; the Malta College for Arts Science and Technology is MIT Media Lab's partner (b) Open Digital Badges (or Badging), powered by the blockchain technology, hold the prospect of being a game-changer in documenting and issuing digital certificates (c) Blockchain promises to be a digital space to host permanent authentication and storage for the increasing credentials market that comprises different types of micro-credentials, nano-degrees, MOOCs, and certificates/badges	(a) No overarching cross-institutional collaboration, yet. For example, Blockcerts is currently not available for the Ethereum blockchain (b) Blockchain is still fraught with serious privacy, security, scalability and storage problems	More case studies are needed about the applications of blockchain in HE settings

Alammary et al. (2019)	A systematic review	Investigate blockchain-based educational applications, or to investigate how blockchain technology is used in education	Not mentioned	Not mentioned	Not mentioned	Currently, blockchain technology is mainly used to: issue and verify academic certificates; evaluate students' professional ability; and share students' competencies and learning achievements	The use of blockchain technology in education is still in its infancy, and is only limited to certain HEIs	(a) Twelve categories of blockchain educational applications: certificates management; evaluating students' professional ability; competencies and learning outcomes management; fees and credits transfer; protecting learning objects; securing collaborative learning environment; enhancing students' interactions in e-learning; competitions management; obtaining digital guardianship consent; copyrights management; supporting lifelong learning; and examination review (b) High security; enhanced students' interactivity; enhanced students' assessments; improving management of students' records; supporting students' career decisions; low cost; identity authentication; better data access control; enhancing trust; ensuring accountability and transparency	(a) Data unavailability and weakening conventional university credentialing (b) Blockchain is fraught with challenges (e.g., privacy, security, scalability, and cost challenges)	Collaboration and partnership between HEIs

- tutoring and advising aided by intelligent tutors and chatbots to offer context-aware and personalized support to students (Khare et al., 2018).

The above-cited AI applications are wide-ranging even though they are heavily oriented to student learning. This means that the most dominant application of AI technologies as stated in the specified studies is learning, or learning support. In this regard, the preferred or the common AI technologies employed to mediate learning are chatbots. The latter (chatbots) have various names such as voice assistants, intelligent assistants, virtual assistants, intelligent tutors, and conversational agents. To this effect, they have multiple educational uses, one of which is to facilitate learning, or to promote learning support (Khare et al., 2018; Luckin et al., 2016; Tegos et al., 2014; also see Chaka and Nkhobo, 2021). In this case, using an AI-powered chatbot to investigate its impact on students' critical thinking (see Goda et al., 2014) serves as one example in which AI can be utilized to facilitate one of the skills regarded as Industry 4.0 skills. Critical thinking, also known as one of the 4C's – together with communication, creativity, and collaboration – is touted as one such key skill that students have to learn for them to be 4IR-ready (Bermúdez & Juárez, 2017; Chaka, 2019, 2020, 2022; Collet et al., 2015). However, using chatbot systems for evaluating their effectiveness on students' memory retention (see Abbasi & Kazi, 2014) tends to be a throwback to the traditional practice of rote learning.

Most of the chatbots identified in the reviewed studies have proper or special names. Some of the proper names given to the chatbots mentioned in the reviewed studies are: OOPLChatbot; Eliza; AdmitHub; Mediator of Education in Technology of Information and Socializer (CA METIS); Snatchbot; Klaudia; Wincent; and Erasmus. In certain instances, such names epitomize what given chatbots are intended to do or are capable of doing as in the case of OOPLChatbot, AdmitHub, and CA METIS. In a different but related instance, Tegos et al. (2014) employed a chatbot called MentorChat to facilitate small group discussions in which undergraduate students had to accomplish different learning tasks in a computer-assisted language learning domain at the Taurida National University of Ukraine. To this end, Luckin et al. (2016) refer to a reverse situation in which artificial students can teach Betty – a virtual intelligent agent – by inputting questions to her in order to keep track of how much she can learn. In this case, students become teachers and learn by teaching, while Betty becomes a student (also see Vanderbilt University, 2019).

Moreover, most of the university courses to which AI technologies were applied as specified in the reviewed articles fall under the all-too-familiar science, technology, engineering and mathematics (STEM) banner, with the remaining few not falling under this banner. Universities notable for their usage of AI technologies are those from the United States of America (U.S.) (5 universities) and Poland (2 universities); and one university each from the United Kingdom (U.K.), Pakistan, Japan, Australia, Brazil, India, and Taiwan. The preponderance of the U.S. universities – and that of European universities

- in this context is glaring (see Table 2). This trend tends to dovetail with what Hinojo-Lucena et al.'s (2019) study found that the U.S. topped other countries in terms of producing literature on AI applications in HE captured by Web of Science and Scopus. It was followed by Romania, Spain and Italy, and the U.K.

In respect of the AI prospects in HE, the following are notable from the reviewed articles:

- deployment of chatbots might have a valuable impact on students' cognition and on students' behaviour in online discussion forums (Goda et al., 2014)
- possibility of personalized, scalable, and affordable learning (Popenici & Kerr, 2017)
- possibility of AI-driven essay grading and possibility of one-on-one tutor engagement (Khare et al., 2018)
- CAs can serve as support tools likely to reduce social isolation in distance education (Krassmann et al., 2018).

In the 4IR era, the idea of personalized, adaptive, scalable, and affordable learning is long overdue. The practice of one-size-fits-all for university students who have diverse learning needs and display different paces of learning is no longer applicable at HEIs. So, it is imperative that HEIs, especially in developing countries, embrace AI technologies for student essay grading and AI technologies that enables one-on-one student engagement. Most importantly, HEIs offering distance education need to utilize AI-powered chatbots to support students with a view to reducing the ever-present social isolation in online learning environments.

Notwithstanding the prospects depicted above, applying AI technologies at HE is fraught with challenges. Some of the challenges flagged are:

- current chatbots are still primitive (Goda et al., 2014)
- AI holds the possibility of casualizing and outsourcing of teaching (Popenici & Kerr, 2017)
- there is no evidence of the application of cognitive tutors at university level yet (Khare et al., 2018)
- conversations involving sustained and meaningful near-human discussions are not yet possible with chatbots (Stachowicz-Stanusch & Amann, 2018).

These challenges are more than concerning in varying degrees. First, in the 4IR epoch, there should be no space for primitive chatbots as technology, especially AI technology, is ever-evolving. This is more so, since AI is one the 4IR technologies that holds the key for HEIs to entering Industry 4.0 and Higher Education 4.0. Second, any temptation to use AI so as to casualize and outsource teaching and learning has to be avoided. Rather, AI can be deployed to make both teaching and learning fun and enjoyable, and to gamify them. Third, AI – in whatever permutations – should not be deployed in HE as a human incarnate or as a human alter ego. As such, it need not have all human attributes, and its lack of all human attributes should not be lamented.

Robotics: Applications, prospects, and challenges in higher education

As highlighted earlier, and as is the case with the preceding section, all of the ten reviewed articles provide explicit usages of the robotic technologies they mention. Besides the usages stated earlier, two more of such usages are:

- facilitating hybrid human-robot collaboration teams for engineering education in virtual worlds, or in virtual learning environments (VLEs) (Richert et al., 2016)
- verifying whether student motivation affects the learning results of arts and humanities students who engaged in different robotics concepts during an educational robotics laboratory (Gabriele et al., 2017).

Viewed collectively, these robotic applications have different foci. However, most of them have a bias towards teaching and learning: employing robotics for teaching and learning, or for examining robotics impact on teaching and learning. In this regard, different types of robots are reported to have been used. Like chatbots, educational robots have multiple uses in relation to teaching and learning as highlighted by the reviewed studies. For instance, a generic robotic usage such as examining how a robotic teaching assistant can be employed at university level (Cooney & Leister, 2019) is line with the exploratory orientation that the use of educational robots still have at most HEIs. This exploratory orientation is also evident in He and Liang's (2019) robotic application of surveying how instructors and students perceive teaching and learning and in Gabriele et al.'s (2017) point mentioned above. One instance of this exploratory use of robotics in HE is Gyebi et al.'s (2017) case study which investigated the efficacy of educational robotics on an undergraduate computer science course. The study concludes that incorporating educational robotics in the said course motivated and engaged students, and helped develop engaging curricula (also cf. Belpaeme et al., 2018).

One aspect of this exploratory orientation of robotic applications as specified in the reviewed articles is their focus on meta-teaching and meta-learning: This refers to applying robotics in certain aspects of HE courses with a view to determining how or whether teaching or learning occurs. It also entails applying robotics for meta-cognitive purposes as suggested by Afari and Kine (2017). A meta-learning element in respect of applying robotics is exemplified by Tuluri et al.'s (2014) case study which leveraged the capabilities of a robotics-based education tool to inspire and engage students to pursue STEM disciplines in HE. This robotics-based educational tool was utilized as an undergraduate research laboratory platform.

As is the case with chatbots, robots bear different proper or special names. Some of the proper names given to the specified robots are: LEGO Mindstorms (LEGO NXT); NAO;

BrainFarm, Parallax sumobot; Baxter; and Sphero. In respect of LEGO, while some of its applications have been integrated into existing university courses (see Eguchi, 2014; Kaya et al., 2017), Yuen et al. (2014) cite other uses of off-the-shelf educational kits such as LEGO NXT and NAO. For example, they point out that LEGO NXT can be used for design and construction purposes, whereas a humanoid like NAO can be utilized by students to learn concepts having to do with navigation and obstacle avoidance, and for acquiring skills for programming and control. The existing university courses to which these robotic technologies were applied are varied, even though most of them are STEM courses. This trend tends to be consonant with Spolaôr and Benitti's (2017) review study in which most of the topics reported by the reviewed papers were from STEM disciplines. Of the specified universities at which these robotic technologies were applied, six of them are U.S. universities, with one each from Uganda, Australia, Germany, Italy, Sweden, and South Korea (see Table 3).

With reference to robotic prospects, the following are some that are stated by the reviewed studies:

- LEGO toolkit exposes students to problem-solving, team work, and project-based learning (PBL) (Danahy et al., 2014)
- LEGO Mindstorm helps students acquire 21st century skills (e.g., collaboration skills, communication skills, creative thinking, critical thinking & problem-solving skills) (Eguchi, 2014)
- virtual simulation lends itself well to be applied to everyday engineering education at HE environments (Richert et al., 2016)
- robotics can be used in an interdisciplinary approach that involves computer science, English and Psychology to foster problem-solving and creative thinking (Spolaôr & Benitti, 2017).

The first two prospects of robotic applications to HE speak to the deployment of educational robots to help students acquire Industry 4.0 skills that are required not only for students, but also for employees, to be future-proof for the demands of 4IR. Such skills (e.g., communication, collaboration, critical thinking, and creative thinking), which are also regarded as 21st-century skills or 4C's (see Bermúdez & Juárez, 2017; Chaka, 2020; Collet et al., 2015), are part of the conventional soft skills (Chaka, 2020). Elsewhere (Chaka, 2020) refers to these Industry 4.0 skills as stylized facts (widely accepted empirical regularities) in line with Helfat's (2007) view. The idea of a virtualized learning or a simulated virtual learning has about it the aura of fusing virtual reality with robotics as one of the topoi of 4IR. Moreover, the notion of interdisciplinarity attached to robotics underscores the interdisciplinary nature of educational robotics. Interdisciplinarity is viewed as one of the survival skills required for the Industry 4.0 era (see Chaka, 2020; Collet et al., 2015).

Despite the prospects offered above, there are attendant challenges confronting robotics. Some of these challenges include the following:

- technical issues, personal challenges and infrastructural challenges (Bada et al., 2013)
- even though NAO offered prompts and delivered praise, it was unable to provide specific feedback on the quality of participant responses (Pennington et al., 2014)
- experimental studies employing quantitative evaluations of educational robotics in the HE sector are still few (Spolaôr & Benitti, 2017)
- in many instances, instructors are not yet well-equipped to use robotics, and in most HEIs, curricula are not yet aligned to accommodate the use of robotics alongside human instructors (He & Liang, 2019).

The afore-cited robotic challenges are glaringly instructive. The first set of challenges in the first bullet epitomizes the situation of many HEIs in most developing countries. For most of these HEIs together with academics who are employed at them, the use of robotics remains a pipe dream. The second challenge manifestly captures some of the structural and technical limitations that not only educational robots, but also other robots (e.g., social, industrial, and manufacturing robots) have. This emphasizes that there are things robots can do, and that there are things they cannot do. The last challenge underlines the educational training deficit and the curricular discrepancies that most HEIs still need to eliminate for them to be able to integrate robotics into their academic programmes. The third challenge highlights the need for more empirical studies that HEIs still have to conduct to evaluate the efficacy of robotics in teaching and learning.

Blockchain: Applications, prospects, and challenges in higher education

As is depicted in Table 4, there are diverse applications that the five studies highlight about blockchain at HEIs. Among these blockchain applications, the most prominent is the one captured in the first bullet. The notion of digital grades, digital credentials, and digital certificates together with the practice of micro-credentialing is a game-changer in the area of grading and credentialing students for courses in which they enrol at HEIs. This is more so as it digitally credits students for nano-courses that they do, as opposed to doing so after the have completed full academic programmes. This practice is largely aided by the security, immutability, and reliability that blockchain technologies (e.g., Ethereum, Blockcerts, and smart contracts) tend to provide (see Jirgensons & Kapenieks, 2018; Tapscott & Tapscott, 2017; also see Coward et al., 2018). One notable application of blockchain relates to managing student course data as in the case of chemistry students (Ezeudu et al., 2018). Another noteworthy blockchain application has to do with supporting and managing academic degrees and summative assessment of learning outcomes, in addition to capturing information about skills, research experience, research interests, and learning experience. This practice, too, lends itself as a game-changer in the management of student records. The same can be said about capturing and managing students' diplomas and certificates as exemplified by the University of Nicosia (Greece) and MIT Media Lab (see Jirgensons & Kapenieks, 2018; Tapscott & Tapscott, 2017). A point worth noting is that there are twelve categories of HE to which blockchain can be applied (see Table 4), some of which are those outlined above.

Some of prospects of that blockchain has for HIEs relate to the followings aspects:

- new pedagogy - Blockchain-powered learning to free up faculty's and students' time and intellectual capital, and cost-cutting (reducing student debt) (Tapscott & Tapscott, 2017)
- real-time contracts and real-time awards through the smart card, mitigating free-riding associated with collaborative learning, and helping students, supervisors and academic advisors plan and monitor students' academic programmes (Chen et al., 2018)
- reducing fraudulent degrees, ability to track student's learning progress and skills acquisition, and providing autonomous time stamping (Ezeudu et al., 2018; also see Table 4).

The advent of a technology that frees up academics' and students' time by remotely tracking, managing, and capturing student learning progress, student learning outcomes, and student academic records, as blockchain promises, is not only attractive, but a welcome relief as well. This is more so when credentialing, tracking, capturing, and time stamping occurs digitally in real time (see Coward et al., 2018). Another compelling proposition offered by blockchain, in this context, is its cost-efficiency for students, and the fact that it eliminates free-riding or piggybacking students in collaborative learning encounters. One example of free-riding related to blockchain-driven education offering is unfair evaluation and false reporting of academic records (Chen et al., 2018).

Pertaining to the challenges that blockchain poses for HEIs, the following stand out:

- blockchain-aided learning is not amenable to human evaluation, and it is not able to assess student essays and classroom presentations (Chen et al., 2018)
- blockchain's immutability does not enable a modification of educational records for legitimate purposes (Ezeudu et al., 2018)
- currently available blockchain technologies are incompatible (Jirgensons & Kapenieks, 2018), and blockchain is still fraught with serious privacy, security, scalability and storage problems (Alammary et al., 2019; Jirgensons & Kapenieks, 2018).

If the aforesaid blockchain challenges (also see Table 4) are anything to go by, then blockchain is a Janus-faced technology whose role in the HE sector is ambivalent. For one thing, if its mediated learning is impervious to human intervention, and if its digitally chained entries and records, which are stored as blocks are not amenable to human correction, then its utilitarian value is questionable. No human record should be left solely to the mercy of a machine without allowing the necessary human modifications. However, Coward et al. (2018) maintain that changing blockchained records requires re-doing hash-based proof-of-work. The inability of blockchain to assess student essays and classroom presentations highlights the limitations it has as a 4IR technology. The same can be said about its privacy, security, scalability, and storage deficiencies. But if a cardinal feature of 4IR technologies is their seamless interoperability, then the incompatibility of both Ethereum and Blockcerts as instances of blockchain technologies flies in the face of that cardinal feature. Besides, it serves as a throwback to the pre-4IR era in which each technology functioned as a silo to the exclusion of other cognate technologies.

Conclusions

The dominant AI technologies employed to mediate student learning and learning support were chatbots, a characteristic feature of which is that they are given proper names (e.g., Eliza, Klaudia, and Erasmus), or names that embody their usage purpose (e.g., OOPLChatbot, AdmitHub, and CA METIS). Some of the student learning and learning support purposes these AI-powered chatbots were meant to serve are to facilitate learning, and to investigate a chatbot's effectiveness on students' critical thinking.

In relation to AI prospects, it emerged that AI-aided chatbots could be used for grading student essays, for one-on-one student engagement, for minimising social isolation in distance learning, and for facilitating personalized, scalable, and affordable learning. This means that HEIs can no longer afford to offer a one-size-fits-all teaching and learning approach to their students anymore. Of the AI challenges flagged, the following stand out: casualizing and outsourcing teaching; AI-aided chatbots lacking near-human engagement; and the lack of cognitive tutors.

Pertaining to the applications of robotics in HEIs, it became manifest that, collectively, such applications had multiple uses, but had a strong bias towards teaching and learning. In addition, such applications were exploratory in nature, and had a strong focus on meta-teaching and meta-learning such as facilitating hybrid human-robot collaboration teams, examining robotics impact on teaching and learning, and investigating how a robotic teaching assistant can be employed at university level. Thus, applying robotics for both meta-teaching and meta-learning, means using it for meta-pedagogical and meta-cognitive purposes. As is the case with chatbots, educational robots are given proper names like Baxter and Sphero. With reference to prospects, the following were foregrounded: facilitating the acquisition of 21st-century skills; fostering simulated virtual learning; and employing robotics for interdisciplinary purposes.

With respect to challenges, technical issues, personal challenges and infrastructural challenges were flagged; so was the ill-preparedness of instructors to use robotics and the fact that most of HE curricula are not aligned to accommodate robotics. Concerning blockchain applications at HEIs, digital grading, digital credentialing, and digital certification together with micro-credentialing were touted as a game-changing practice in the area of grading and credentialing students for courses they do at HEIs.

Implications

In view of the points discussed above, there are implications that are relevant for research and practice in technology enhanced learning (TEL). This is more so as the sets of technologies reviewed in this paper are part of 4IR. As elaborated under the overview section, the reviewed cognate 4IR technologies have a direct bearing on TEL in terms of its research and practice. For instance, concerning AI, chatbots emerged as the key technologies for student learning and support. In this case, chatbots, especially AI-powered chatbots, have other applications for student learning and support, in addition to those highlighted above. Some of these applications include:

- automating frequently asked questions (FAQs) that can be answered by chatbots (cf. Chaka & Nkhobo, 2021; Getsmarter, 2022)
- personalized, adaptive learning tailored to student needs and student learning behaviours that is driven by both AI and machine learning (cf. Bucea-Manea-Ţoniş et al., 2022)
- AI tutors for intelligent tutoring
- Automatic grading (e.g., grading tests, assignments, essays, and quizzes) and personalized assessments, which offer individual and group analysis (see Dharmadhikari, 2022).

However, as pointed out earlier, there are still challenges attendant to employing AI for teaching and learning. For example, there are aspects of teaching and learning that can best be dealt with by human minds, and which cannot be outsourced to AI technologies. This implies that artificial intelligence (including artificial neural networks) is not an alter ego of or a substitute for human intelligence. Rather, an augmentation between the two must always be sought.

Regarding robotics, particularly educational robotics, it is clear that it can be utilized for: acquiring Industry 4.0 skills (as is the case with AI-aided chatbots); simulated virtual learning; and promoting interdisciplinary teaching and learning. Additionally, humanoid robots such as NAO can be integrated into gamification (learning through computer games) to make learning more fun, casual, and exciting. This is the case with areas like science, technology, engineering, mathematics, computer science, and literacy. Needless to say that educational robotics also has a place in other academic fields as well. Moreover, adaptive robotic tutors can be provided to support students for preparing for course examinations (Donnermann et al., 2022), and for preparing for course tests and assignments. Nonetheless, as pointed out earlier, the challenges for implementing robotics are self-explanatory: most HEIs (especially those in developing countries) have technical and infrastructural challenges; most academics are under-prepared to use robotics; and most of HE curricula are not yet robotics-compliant, and thus, are not 4IR-ready.

In respect of blockchain, what stands out is that nano-courses and nano-learning have to be validated and credited accordingly, and given the credibility they deserve. Nano-courses and nano-learning are also micro-credentials (mini-qualifications about knowledge, skills, and/or experience acquired in relation to a given subject area module) and micro-learning (see Burrows et al., 2022). The same can be said about blockchain student assessment. These game-changing blockchain applications resonate with blockchain prospects in which real-time contracting and time stamping of learning, and in which the tracking, managing, and capturing of student learning progress, student learning outcomes, and student academic records can be executed remotely and seamlessly. This will usher in the era of real-time student record management that is immutable and verifiable, on the one hand, and that is decentralized and accessible to students, on the other hand.

Nevertheless, like any other technology, blockchain has its shortcomings. Prominent among these shortcomings are the intractability of its records to human modification; its privacy, security, scalability, and storage deficiencies; and the non-interoperability of some of its technologies (e.g., Ethereum and Blockcerts). This makes it a double-edged 4IR technology. Most importantly, the fact that it cannot yet assess student essays and classroom presentations, two of the key areas that consume a lot of instructors' time, is likely to make it be seen as a bête noire by most instructors for now.

Limitations

As is the case with most review studies, the current study has limitations. Firstly, the study used only online databases and online search engines to search for journal articles that were reviewed. As such, it had a bias toward online journal articles as no hard copies of journal articles were used. But, the decision to utilize online articles was informed by the fact that more information on the three 4IR technologies (AI, robotics and blockchain) is more readily available online than from hard copies. Secondly, the study is slanted toward peer-reviewed journal articles as opposed to the non-peer reviewed ones. The latter often contain useful information on 4IR issues, however, their being regarded as grey literature made them doubtful candidates for the current study.

Overall, even though 4IR is not one monolithic process, but rather multiple technological processes involving several technologies, it is plausible to say that the current review study provides evidence that 4IR is making inroads in the HE sector. However, its impact is still to be felt in this sector given that most HEIs have not yet fully embraced it. This became more glaring when most HEIs were forced to suddenly and temporarily stop their operations at the beginning of the COVID-19 pandemic. If anything, 4IR ought to have helped HEIs to weather the pandemic storm. But that was not the case. Nonetheless, the prospects offered by 4IR as discussed in this review, and those provided by the other 4IR technologies not discussed in this study, are unlimited. It is actually entities, HEIs included, that must embrace and deploy 4IR technologies as technologies cannot deploy themselves on behalf of entities.

Abbreviations

4IR: Fourth industrial revolution; AdmitHub: A chatbot technology powered by artificial intelligence; AI: Artificial intelligence; AIED: Artificial intelligence in education; AR: Augmented reality; EFL: English as a foreign language; ERIC: Education Resources Information Center; FAQs: Frequently asked questions; HE: Higher education; HEIs: Higher education institutions; IIoT: Industrial Internet of Things; IoT: Internet of Things; LEGO NXT: A programmable robotics kit owed by LEGO; LEGO: leg godt (Danish); MIT: Massachusetts Institute of Technology; NAO: a programmable, autonomous humanoid robot owned by Aldebaran Robotics; PoW: Point-of-Work; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RQs: Research questions; STEM: Science, technology, engineering and mathematics; TEL: Technology enhanced learning; U.K.: The United Kingdom; U.S.: The United States; VLEs: Virtual learning environments; VR: Virtual reality; Web 1.0: The first World Wide Web that was static; Web 2.0: The second World Wide Web that was interactive; Web 3.0: The World Wide Web that is intelligent and that uses semantic agents; Zcash: Zerocash.

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