Artificial Intelligence in the Fourth Industrial Revolution to Educate for Sustainable Development

L'intelligence artificielle dans la quatrième révolution industrielle pour éduquer au développement durable

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Abstract

There has been increasing interest in the use of Fourth Industrial Revolution technologies such as artificial intelligence to help achieve the Sustainable Development Goals. Recently, multilateral organizations have sponsored initiatives to make countries aware of the benefits of using artificial intelligence for sustainable development and to educate citizens to improve quality of life. This paper explores aspects of employing artificial intelligence for sustainable development, with a focus on lifelong learning, and inclusive and equitable quality education. Data are drawn from a thematic review of 32 academic peer-reviewed journal articles and interviews with six international experts. Findings include examples of benefits and challenges of artificial intelligence to address sustainable development and education.

Keywords: Artificial intelligence; Fourth Industrial Revolution; 4IR; Online learning; SDG4; Sustainable development goals

Résumé

Il y a eu un intérêt croissant sur l'utilisation des technologies de la quatrième révolution industrielle (4RI), telles que l'intelligence artificielle, pour contribuer à la réalisation des objectifs de développement durable (ODD). Récemment, des organisations multilatérales ont parrainé des initiatives visant à sensibiliser les pays aux avantages de l'utilisation de l'intelligence artificielle pour le développement durable et à éduquer les citoyens pour améliorer la qualité de vie. Cet article explore les aspects de l'utilisation de l'intelligence artificielle pour le développement durable, en mettant l'accent sur l'apprentissage tout au long de la vie et l'éducation de qualité inclusive et équitable. Les données

sont tirées d'une revue thématique de 32 articles de journaux académiques évalués par des pairs et d'entretiens avec six experts internationaux. Les résultats comprennent des exemples d'avantages et de défis de l'intelligence artificielle pour aborder le développement durable et l'éducation.

Mots-clés : Intelligence artificielle ; quatrième révolution industrielle ; 4RI ; apprentissage en ligne ; ODD4 ; objectifs de développement durable

Introduction

There has been increasing interest in the use of Fourth Industrial Revolution (4IR) technologies, such as artificial intelligence (AI), the Internet of Things, blockchain, and others, to help achieve the sustainable development goals (SDGs). Recently, organizations such as UNESCO (2019a, 2019b) and the World Economic Forum (2020) have emphasized the use of artificial intelligence for sustainable development. In 2019, two UNESCO conferences were named *Artificial Intelligence for Sustainable Development* and *International Conference on Artificial Intelligence and Education: Planning Education in the AI Era: Lead the Leap*. Leapfrogging has been a common metaphor in relation to sustainable development ("The Leapfrog Model", 2017), with the notion that lessons learned from western industrialisation can expedite modernization elsewhere. China's state-led model was a case in point (Xue et al., 2018), as were the four Asian Tigers (Hong Kong, Singapore, South Korea, and Taiwan) that pre-dated China's rise starting in the late 1970s by about 20 years. With a narrower focus, this paper contemplates how far the emerging world can gain, if not exploit, the promise of the 4IR in the context of education, which is universally agreed as a cornerstone to sustainable development. To advance this conversation, it is imperative to consider alongside the perceived benefits, the existing challenges. Top of the list is infrastructure (Fayomi et al., 2019; Pollitzer, 2019), with other matters that include security, ethics, and employment. Those in repetitive task or low skilled jobs, where a large proportion of the world's workforce is located, are most at-risk to the onslaught of the 4IR, and particularly as it relates to automation (Habanik et al. 2019; Oberc et al., 2019). While governments are increasingly aware of these looming realities, they are also prone to being reactive rather than proactive on issues, particularly in functional democracies, where political cycles focus politicians' attention on the near-term rather than the long-term. As a means to consider what opportunities lie ahead, this paper draws on inputs from AI experts around the world on what is needed to prepare and actively participate in the 4IR. Aspects on the development of artificial intelligence for sustainable development, and taking a multidisciplinary approach to consider uses, innovations, ethics, access, privacy, security, and so on will be delineated. The aim is to develop an informed, collective understanding of the benefits and challenges in present and which may arise from the subsequent adoption of AI for achieving the SDGs, especially in relation to SDG4, which focuses on education (Visvizi, 2022).

Guiding this paper are the following two research questions:

1. What role can AI play to educate citizens for sustainable development?

2. What role can AI play to help achieve the sustainable development goals?

The Fourth Industrial Revolution and Sustainable Development

Different sectors of society are experiencing the 4IR. It is driven by the digital revolution, which combines the physical, digital, and biological domains into daily life. Tools that were previously offline and required our physical presence to operate are now controlled remotely and at a finger's touch facilitated through the Internet. The underlying premise of the 4IR is to inform the next level of societal advancement, as was the case in the three earlier industrial revolutions. In present day, the 4IR is predicated on the ubiquity, connectivity, and independence of digital technologies. For sustainable development, the question remains about how 4IR may alleviate poverty, widen access to quality learning, and protect the environment.

The UNESCO report *Meeting Commitments: Are Countries on Track to Achieve SDG4?* indicated that meeting the SDG targets were not on track and were exacerbated by the inability to collect the necessary data (2019b). Artificial intelligence is one proposed solution to automate data mining. Such advancements cannot exist outside the social world. Citizens need to be educated and society must have some say over how AI will affect their lives. The world is irreversibly interconnected, and this means enhanced capabilities to address enduring economic, social, and environmental problems.

Artificial intelligence can be defined as "a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments" (Vincent-Lancrin & van der Vlies, 2020, p. 7). The link to education is in the provision of flexible and personalised learning that can more broadly lead to the acquisition of skills, improved livelihoods, and ultimately sustainable development (Rizk, 2020; Wozniak, 2020). The United Nations (UN) has defined sustainable development as a movement for ensuring sustainable well-being for all United Nations (2015). Through the 17 sustainable development goals, led and coordinated by UNESCO, the UN has aimed to address the persisting global issues of poverty, inequality, conflict, climate change, and environmental degradation (Ghobakhloo, 2020). Ultimately the intent is for all sectors of society to embrace efforts to improve the livelihoods of the world's residents, and particularly the marginalized (Pollitzer, 2019; Rosa, 2017; United Nations, 2015). The link between AI and the SDGs can be considered in the context of empowerment. Rubin and Brown (2019) posited that artificial intelligence was still in a nascent stage but its applications to learn about students' interests, habits, and patterns in order to promote learning experiences based on unique identified needs, was emerging.

> If this (artificial intelligence) technology is to be accessible to all, it must be taught everywhere. It is through education that it will be placed in the hands of those who need it most. And I guarantee you that if you give them the means, people will find solutions to their own problems. (Cissé, 2018, p. 20)

UNESCO has been exploring the possible contributions of AI to inclusive education and assessing its potential impact on the future of learning (Azoulay, 2018, p. 38). Artificial intelligence has the potential to improve the welfare of people; contribute to positive sustainable global economic activity; increase innovation and productivity; and help with responses to key global challenges, such as climate

change, health crises, resource scarcity, and discrimination (OECD, 2019b). The OECD and other organisations have seen the potential for AI to contribute to achieving the SDGs with specific acknowledgment of its role in education (OECD, 2019a, p. 4).

Literature Review

Education 4.0 in Sustainable Development

The *United Nations Sustainable Development 2030 Agenda* contains 17 SDGs and 169 targets intended to help guide all sectors of society to improve the livelihoods of the world's residents (Pollitzer, 2019; Rosa, 2017; United Nations, 2015). SDG4 on education aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (Rosa, 2017, p. 14).

The link to AI in education is personalisation and self-organising relative to instruction and support to learners (Mitra, 2014, 2019). Learning will move toward individualisation and learner centeredness, due to AI (Aker & Herrera, 2020; Chai & Kong, 2017; Mitra, 2014; Popenici & Kerr, 2017). Emerging technologies will dramatically change the role of teachers, with many becoming digital teachers, using deep-learning technologies such as AI (Ally, 2019; Ally & Wark, 2019a). The World Economic Forum (2017) foresaw teachers having to adopt AI to teach in the 4IR. Are these kinds of interventions achievable in countries at all income levels? Not at present. There is little reason, however, to overlook the role of AI in varied contexts and to consider what uses exist, or potentially exist, supported by conditions, cultures, and histories that are locally situated.

Online Learning and Machine Learning in Education for Sustainable Development

Characterized as the desire for interactive, co-created, personalised, on-demand, and perpetual learning, online learning is surging in demand with the transition into the 4IR era (Ally & Wark, 2019b; Buasuwan, 2018; Wan Chik & Arokiasamy, 2019). Increasingly, traditional formal classroom-based learning is being supplanted by online and mixed-reality learning environments that can provide timely and relevant learning (Block et al., 2018; Grodotzki et al., 2018; Mavrikios et al., 2019; Mourtzis et al., 2018). Moreover, escalating access to online and mobile learning platforms (Aziz Hussin, 2018; Bhattacharjee et al., 2018; Block et al., 2018; J. Chen et al., 2018; Jia et al., 2019; Lou, 2018; Stock et al., 2018), including a recent initiative to develop a global, AI-enabled, open-source, online learning platform (Duraiappah, 2018), suggests that in the near future, online learning will supersede the demand for traditional face-to-face learning (Ally & Wark, 2019b).

Duraiappah's (2018) article, "Artificial Intelligence for Education," described an online prototype platform called Collective Human Intelligence that allows, "educators and learners to develop curriculum, lesson plans and assessments in an interactive, immersive and experiential environment, which is supported by AI that is able to provide feedback to students and educators of progress and suggestions to improve learning" (p. 1). One feature of this globally accessible online platform is the assignment of a personal bot to a child. This bot draws upon collective knowledge from

learners across the globe, while tailoring instructional activities and tasks to meet the unique needs of the learner to whom it is assigned.

Machine learning (ML) is a sub-field of AI associated with machines' ability to learn inductively (Buckreus & Ally, 2020). Machine learning applications are designed to process sets of historical observations (data records) to infer new patterns or rules arising from the data. Whenever the data are changed, an ML algorithm *learns*. An algorithm learns in the sense that it picks up the modified patterns in each data set and then presents or predicts a new result to personalise the instructional activities for the learner. The system will learn about the learner as the two progresses, then make decisions that will optimise instructional activities.

Kučak et al. (2018) conducted a systematic review to determine the value of machine learning in the field of education. They concluded that ML made a significant contribution in numerous areas of education: (a) prediction of learner performance, (b) fair and equitable assessment of learning, (c) improved learner retention, and (d) provision of administrative duties for educators. Moreover, ML could offer personalised assessment by eliminating standardised testing, and providing "constant feedback to teachers, students and parents about how the student learns, the support they need and the progress they are making towards their learning goals" (p. 409).

Methodology

Data was generated from a review of relevant literature and interviews with international experts in 4IR, AI, and other emerging technologies. The aim was to answer the following research questions:

1. What role can AI play to educate citizens for sustainable development?

2. What role can AI play to help achieve the sustainable development goals?

The literature included in this study came from four sources: (a) the researchers' personal libraries, (b) a systematic review of pertinent peer-reviewed journal articles, (c) final reports from world organisations such as the World Economic Forum and UNESCO, and (d) interviewee publications, reports, links to web resources, and other recommended resources. This study used well-established systematic review processes (Gough et al., 2012; Hemingway & Brereton, 2009; Oakley, 2012). Ethics approval from an accredited Canadian university was obtained to conduct the study.

Systematic Literature Review

A university meta-database search engine was used to conduct a comprehensive search of relevant academic peer-reviewed journal articles. Three inclusion criteria were established. First, the articles had to be in an English-language, peer-reviewed journal located in a university-subscribed or open-access journal database and second, published between January 1, 2017, and December 31, 2019. Third, the article content had to address at least one of the research questions. A total of 219 titles were initially selected (see Table 1).

Table 1

Number of Journal Articles Identified by Journal Database

Journal database	Number of journal titles
Science direct	125
Academic search complete	56
Business source complete	32
SocINDEX with full text	13
Academic one file	12
Expanded academic ASAP	5
General one file	4
Canada In Context	3
Emerald insight	3
General reference center gold	3
Literature resource center	3
Student resources in context	3
Communication & mass media complete	2
CINAHL plus with full text	1
InfoTrac computer database	1
Total number of titles	266
Less: duplicates	– 47
Total number of unique titles	219

After several rounds of discussion and consensus building, 78 were selected. There were 36 articles that did not address at least one of this study's research questions. A total of 32 articles matched all the inclusion criteria for analysis. (These 32 articles are listed with an asterisk in the reference section.)

Interviews with 4IR Experts

Based upon their knowledge and expertise in the identified topic areas, 48 4IR international experts from academic, government, private enterprise, and civil service sectors were invited to join the study. Of these, 12 experts completed interviews, and herein are referred to as respondents. Recorded interviews were conducted by telephone or online. Each respondent was asked to edit and verify the transcription of their interview before the transcript was processed for analysis purposes.

The results reported herein include data from six interviews. They were selected for their ability to provide a rich picture of the phenomena under study, in a manner that added greatest value in terms of the project's aims. In terms of experience, the experience in the 4IR sector ranged from four to more than 30 years. At the time of the study, five were employed in the field of academia. Three taught university classes; one of these was also an administrative leader. Two respondents worked in non-teaching university positions.

Results and Discussion

This section is based upon cumulative data results drawn from six interviews and the previously described literature sources.
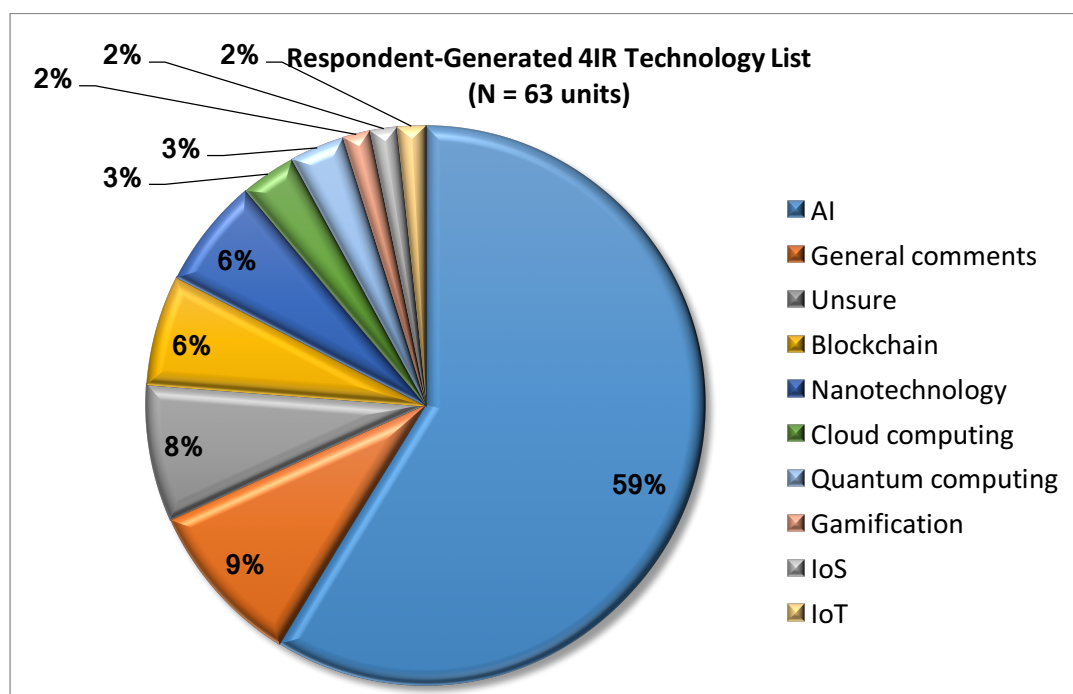
Interview Data Analysis Process

The highest level of coding labels (or "parent codes") in the qualitative coding framework were drawn from the main sections of the interview script. Sub-code labels (or "child codes") and sub-sub-code labels (or "grandchild codes") were established under the parent codes as two researchers coded the first two interview transcripts together. The first researcher then coded a third transcript, and the second researcher reviewed the coding, ascertaining 100% agreement with the first researcher. Coding of the remaining three transcripts followed this pattern of the first researcher doing the initial coding and the second coder verifying the results. Between coders, 100% agreement was achieved throughout this process.

What Are the Emerging Technologies?

A total of 63 units were coded in response to the interview question to list the emerging technologies. The technology most discussed by respondents was AI (n = 37 units, or 59 per cent of all units coded to this category; see Figure 1). One respondent-recommended resource was the book *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning* (Holmes et al., 2019), wherein a taxonomy of AI technologies for learning was presented. This taxonomy included intelligent tutoring systems, dialogue-based tutoring systems, exploratory learning environments, automatic writing evaluation, learning network orchestrators, and AI-driven language learning.

The pervasiveness of AI technologies for educational purposes was evident not only in the interview discussions but also in the literature. Twenty-five of the 32 articles mentioned AI in general or discussed specific AI technologies in relation to the SDGs.

Figure 1

List of Technologies Generated by Respondents

Respondent-Generated 4IR Technology List (N = 63 units)

- AI — 59%
- General comments — 9%
- Unsure — 8%
- Blockchain — 6%
- Nanotechnology — 6%
- Cloud computing — 3%
- Quantum computing — 3%
- Gamification — 2%
- IoS — 2%
- IoT — 2%

Note. (N = 63 units; 1 unit = 1 sentence, expressed by percentage)

How Can These Emerging Technologies Be Used in Education?

Data collected from the reviewed literature and respondent interviews focused upon four key themes in addressing how emerging 4IR technologies could be used to educate the masses. These themes were:

- access to learning
- lifelong learning
- employing AI learning technologies
- personalised learning

Access to Learning

A prevalent theme emerging from the data was access to learning. When talking about current access to education, one respondent relayed the following observation:

> At these [international] conferences I met people from the developing world, and it was clear, time and time again, that they were saying, "Why are we talking about AI in education when we don't even have the infrastructure? We don't have electricity. We don't have Internet access. We don't have the hardware that is necessary."

The sentiments expressed by interviewees on infrastructure was echoed in the reviewed literature (Fayomi et al., 2019), with another interviewee noting the bias in AI toward rich world countries. That said, there is better infrastructure around the globe than ever before with improved links in particular between urban and rural centres (Fennell et al., 2018). It has only been 15 years since the iPhone's launch in 2007 ushering in rapid expansion of smartphones worldwide, including numerous brands that are as inexpensive as USD $50. As well, the cost for technology has decreased and continues to be inversely proportional with computing power. Part of the problem, noted by one interviewee is that,

> decision-makers are not AI practitioners or trained in AI. They're the ones that we're relying on to create policies that allow companies to grow, yes, but also to keep our data and institutions secure, and keep our personal data and information in our hands. They are supposed to create the policies, the curricula, and the plans for education going forward. And yet very few have a deep understanding of what AI can do or how it works.

As it relates to education, governments and educational decision-makers need to be aware that AI is expected to significantly transform the way that educators work by offering teaching aids and relieving them of repetitive or mundane tasks, such as keeping records and sending out notifications or reminders (Ellahi et al., 2019). Furthermore, it is anticipated that AI will revolutionise personalised learning, improve access to knowledge, and potentially foster greater inclusivity (Azoulay, 2018; Duraiappah, 2018; Hodson, n.d.; UNESCO, 2019a).

Lifelong Learning

 Most of the literature and interview data surrounded the recognition of lifelong learning in the 4IR era. Some of the data discussed how emerging technologies, especially AI, might support lifelong learning goals. One respondent concluded the interview discussion on lifelong learning by postulating, "digital assistants could be used in ways to help with setting lifelong learning goals."

This is aligned with how Kemato (2018) detailed how AI could be used to create parallel micro-level skill development models for a learner, by not only tracking skill acquisition but also presenting job opportunity choices and career path scenarios. When prerequisite skills are absent, AI that is cognisant of existing curricular options could then recommend learning resources and track the learner's progress towards the attainment of these skills. "In other words, AI can produce online courses from identified skills and so bring vocational training and lifelong learning for billions of learners" (p. 25).

Employing AI Learning Technologies

A myriad of examples of AI learning technologies and how they can be used in the 4IR emerged from the reviewed literature and interview data. The most common AI topics associated with this theme focused upon immersive learning, machine learning, and learning platforms. AI-driven game-based learning was mentioned in some articles and one interview.

General statements or examples were provided of how emerging technologies can be used to facilitate personalised learning, as the following interview comment illustrates:

So, this is a broad concept, and there are a lot of technologies that are developed around this concept, like how you personalise learning to a particular individual speed, or liking, or all other things. So, if they are doing things at their own pace, they can always try the same thing even if they are doing it wrong, they can try it for 10–15 times.

What AI Technologies Can Contribute to Sustainable Development?

When interviewees were asked to identify what emerging 4IR technologies could contribute to sustainable development, the prevalent response was, "All of them." As one respondent put it, these technologies "optimise human behaviours and human capabilities." Another respondent said:

There's nothing in this world that will not be impacted by AI technology. In terms of 4IR technologies, I would say that AI is by far the most mature, is the one having the most current impact, and in the long run, the one that will have the deepest and most ramifications on society.

Interviewees provided several examples where AI technologies can enhance inclusivity and empowerment for global citizens. To illustrate, one interviewee pointed out that the Internet represents only five per cent of the world's languages, with English persisting as the digital lingua franca (Hariharasudan & Kot, 2018). The interviewee described how one learning/neural network technology, natural language processing, offers an equitable solution:

I think natural language processing is the crux of pretty much everything if we want to talk about equitable access, or worldwide or international equality in any way going forward through the fourth industrial revolution. So, I think these types of translation-based AIs and really anything that can support minority language speakers in accessing information is going to be the most helpful.

According to another interviewee, the employment of natural language processing also facilitates better communication between governments, other public institutions, and citizens, especially in countries where numerous languages co-exist, as in India or Papua New Guinea.

One pilot project in India explored ways in which AI can facilitate the prediction and diagnosis of prevalent diseases, such as heart ailments (Javaid & Haleem, 2019). Another project focused on the development of an AI app that can read and transform medical practitioners' handwriting into various digital formats to facilitate the processing of medical prescriptions and other medical information (Javaid & Haleem, 2019). There are also chatbots being designed to help patients' complete forms; others are employed to reduce patients' anxiety. Global research projects could examine the viability of such initiatives for providing better health services to disadvantaged citizens around the world. The education sector can learn from how AI is used in non-educational sectors. Cues from some sectors can inform progress in others and a multidisciplinary approach to solving issues is also part of the SDGs, and in particular, SDG17, which focuses on partnerships to reach the SDGs by 2030.

Conclusion

What Role Can the 4IR and AI Play in Education?

The greatest role that the 4IR and AI can play in sustainable development is to improve accessibility. In the context of AI, equal access to technologies, employment opportunities and education are key. A prominent theme arising from this study is the pivotal function of education in fostering greater equality. Yet study results also underscore the urgent need to educate and support teachers, learners, and other global citizens in the transition to the 4IR era and its influence on education. Future projects and other global initiatives could play a vital role in facilitating these transformations by offering educational stakeholders timely, inexpensive, and professional development and training resources, such as making Massive Open Online Courses (MOOCs) and Open Education Resources (OERs) more intelligent to cater for learners' individual needs.

Educational briefs, brochures, and resources for government administrators, policy makers, educational stakeholders and the general public that counter the myths and fears surrounding 4IR technologies are crucial (Xue et al., 2018). Interviews with expert respondents clarified that teachers do not need to have advanced training in AI but do require a basic understanding of AI to address, if not neutralise, their misunderstandings or lack of knowledge, and by association create an environment for their learners that embraces rather than excludes technology. Government administrators, policy makers, and educational stakeholders need exposure to how 4IR technologies can be used for sustainable development in their regional or national contexts. Future global activities could employ 4IR technologies to create and distribute educational packages that describe and exemplify how these technologies can be used for the benefit of humans.

Also, 4IR technologies can be incorporated into future global enterprises to track, monitor, and suggest recommendations for improved services to global citizens. For example, AI and blockchain can be employed with respect to a particular educational initiative; to record, monitor, assess and make recommendations for improvement, or access student records and credentials. The blockchain can offer an open, transparent, reliable, and trustworthy ledger of interactions and transactions among all stakeholders (G. Chen et al., 2018; Hidayatno et al., 2019; Hughes et al., 2019; Muhuri et al., 2019; Stock et al., 2018). Artificial intelligence would learn from these activities and thereby be able to offer suggestions for future projects.

Other needed resources are educational packages aimed at developing: (a) essential numeracy, literacy, and digital skills, (b) social, moral, and critical thinking capacities, along with creative, problem-solving capacities, that engender emotional intelligence, flexibility and adaptability, and (c) lifelong learning opportunities (Ally & Wark, 2019a, 2019b; Aoki, 2020; Aziz Hussin, 2018; Brown & Keep, 2018; Butler-Adam, 2018; Gusmão Caiado et al., 2018; Lou, 2018; Mourtzis et al., 2018).

What Role Can 4IR and AI Play in Sustainable Development?

Artificial intelligence and other 4IR technologies can be used to enhance cultural, social, economic, and environmental sustainability if governments, industry, and citizens have the access and

know-how to employ these technologies. Donaires et al. (2018) identified three levels of societal effort to achieve sustainability: individual, organisational, and worldwide. The most critical step towards sustainability is at the individual level, where personal attitudes about the right to lead a self-centred lifestyle can be replaced by a willingness to embrace co-operative decision making and living, as well as an ethos of self-denial and self-sacrifice (de Raadt & de Raadt, 2014). The challenge faced at the organisational level is how to balance economic demands against internal social and environmental costs when developing a systematic approach to sustainability (Donaires et al., 2018). Globally, the dilemma is how to measure, monitor, and assess what progress is being made towards global sustainability (Donaires et al., 2018; Schwaninger, 2015; UNESCO, 2019b).

Artificial intelligence and other 4IR technologies can be employed to increase equality among global citizens as the world enters the 4IR era. The primary key to achieving the SDGs is the provision of quality education for all. Future global projects need to support research, innovation, financial initiatives, and other incentives aimed at providing equitable, affordable access to 4IR technologies.

Future of AI for Education in the Fourth Industrial Revolution

Emerging digital technologies will converge to create cyber-physical systems that will transform how factories operate, how manufacturing processes are controlled, how healthcare and transport services are rendered, and what kind of consumer markets can be created (Luthra & Mangla, 2018; Mourtzis et al., 2019; Pollitzer, 2019; Zabidin et al., 2019). Under the cloud of the 2019 Coronavirus pandemic, education systems– though not universally –have shifted to an online format that is increasingly learner centred. The use of AI can personalise learning for individual learners, simulating intelligent tutors. According to the UNESCO Institute for Statistics (2016), the world needs 69 million teachers to achieve SDG4. Having intelligent tutors could compensate for this shortage of teachers.

The UNESCO report *I'd Blush if I Could* (West et al., 2019) detailed the global gender divide: "Today, females are 25 per cent less likely than males to know how to leverage digital technology for basic purposes, four times less likely to know how to programme computers and 13 times less likely to file for a technology patent" (p. 4). The report pointed out that AI technologies often reinforce gender bias. This phenomenon is likely due to the dominant number of AI designers who are male, and some whom have modeled chauvinistic behaviour through disparaging remarks or subtle actions (Richardson, 2015; West et al., 2019). An effective way to reduce gender bias in AI is for countries, international organisations, and educational institutions to continue to promote gender equality policies, and to financially support the inclusion of females in digital education programmes, as well as to provide incentives that encourage industries to hire women in the field of AI.

Educating citizens around the world will be the key to help achieve the SDGs (Doucet et al., 2018). Futurists predict that education will become self-organising, and technology will play a major role in delivering instruction and support to learners (Mitra, 2014, 2019). In this context, learning will increasingly become individualised and learner-centred due to 4IR technologies such as AI, learning analytics, and the Internet of Things (IoT) (Chai & Kong, 2017; Popenici & Kerr, 2017). The 4IR era

will certainly change the role of teachers, who will then become 4IR or digital teachers, using deep-learning technologies such as AI, robotics, big data, and the IoT (Ally, 2019; Bryant et al., 2020). The AI divide and 4IR divide will need to be bridged so that teachers and learners can be well-prepared to use emerging technologies in teaching and learning. In addition, education will play an important role in assisting the world with transitioning into the 4IR to achieve the UNESCO SDGs by 2030. This will require a new lifelong, learner-centred educational paradigm, and learning environments that foster critical thinking, innovation, moral judgment, social inclusion, and ecological sustainability (Aoki, 2020). AI and machine learning can complement other digital education initiatives for educating citizens to help achieve the SDGs.

We posit that 4IR technologies, which are underutilised in education when compared to other sectors in society, provide an avenue for education to contribute to sustainable development goals. Outside of the education sector, organisations need to educate employees on social skills and trustworthiness so that AI can be used for good in society (Smolenski, 2016). Audrey Azoulay (2018), the Director-General of UNESCO, commented:

> AI can be a fantastic opportunity to achieve the goals set by the 2030 Agenda, but that means addressing the ethical issues it presents. AI can allow better risk assessment; enabling more accurate forecasting and faster knowledge-sharing; by offering innovative solutions in the fields of education, health, ecology, urbanism, and the creative industries; and by improving standards of living and our daily well‑ being. (p. 37)

Vinuesa et al. (2020) claimed no study has examined the merits of AI to inform the UNESCO SDGs, despite the potential of AI. Artificial intelligence use for education and sustainable development relies on multiple sectors of society coming together in research and development on the topic.

References

An asterisk (*) denotes an article that matched all the study's inclusion criteria.

Aker, M., & Herrera, L. J. P. (2020). Smart literacy learning in the 21st century: Facilitating PBSL pedagogic collaborative clouds. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 429–446). Springer.

Ally, M. (2019). Competency profile of the digital and online teacher in future education. *International Review of Research in Open and Distributed Learning, 20*(2), 302–318. https://doi.org/10.19173/irrodl.v20i2.4206

Ally, M., & Wark, N. (2019a, September). *Learning for sustainable development in the Fourth Industrial Revolution.* In Proceedings of the Pan-Commonwealth Forum 9 (PCF9). Commonwealth of Learning. http://oasis.col.org/handle/11599/3393

Ally, M., & Wark, N. (2019b, November). *Online education in the Fourth Industrial Revolution era.* [Paper presentation]. International Council on Distance Education (ICDE) World Conference on Online Learning (WCOL) 2019, Dublin, Ireland. https://wcol2019.ie/wp-content/uploads/presentations/CP_052,%20ALLY.pdf

Aoki, K. (2020). Technologies for lifelong and lifewide learning and recognition: A vision for the future. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 41–52). Springer.

*Aziz Hussin, A. (2018). Education 4.0 made simple: Ideas for teaching. *International Journal of Education and Literacy Studies, 6*(3), 92-98. http://dx.doi.org/10.7575/aiac.ijels.v.6n.3

Azoulay, A. (2018). Making the most of artificial intelligence. *The UNESCO Courier, 3*(July-September), 36-39. https://en.unesco.org/courier/2018-3/audrey-azoulay-making-most-artificial-intelligence

*Bhattacharjee, D., Paul, A., Kim, J. H., & Karthigaikumar, P. (2018). An immersive learning model using evolutionary learning. *Computers & Electrical Engineering, 65*, 236–249. https://doi.org/10.1016/j.compeleceng.2017.08.023

*Block, C., Kreimeier, D., & Kuhlenkötter, B. (2018). Holistic approach for teaching IT skills in a production environment. *Procedia Manufacturing, 23,* 57–62. https://doi.org/10.1016/j.promfg.2018.03.161

*Brown, P., & Keep, E. (2018). Rethinking the race between education and technology. *Issues in Science and Technology, 1,* 31–39.

Bryant, J., Heitz, C., Sanghvi, S., & Wagle, D. (2020). *How artificial intelligence will impact K-12 teachers.* McKinsey & Company. https://www.mckinsey.com/industries/social-sector/our-insights/how-artificial-intelligence-will-impact-k-12-teachers

*Buasuwan, P. (2018). Rethinking Thai higher education for Thai 4.0. *Asian Education and Development, 7*(2), 157–173. https://doi.org/10.1108/AEDS-07-2017-0072

Buckreus, K., & Ally, M. (2020). "Smart" practices: Machine intelligence for transforming pedagogy and learning. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 53–74). Springer.

*Butler-Adam, J. (2018). The Fourth Industrial Revolution and education. *South African Journal of Science, 114*(5/6), 1. https://doi.org/10.17159/sajs.2018/a0271

Chai, C. S., & Kong, S. C. (2017). Professional learning for 21st century education. *Journal of Computers in Education, 4*(1), 1-4. https://doi.org/10.1007/s40692-016-0069-y

*Chen, G., Xu, B., Lu, M., & Chen, N.-S. (2018). Exploring blockchain technology and its potential applications for education. *Smart Learning Environments, 5*(1), 1. https://doi.org/10.1186/s40561-017-0050-x

*Chen, J., Yin, X., & Mei, L. (2018). Holistic innovation: An emerging innovation paradigm. *International Journal of Innovation Studies, 2*(1), 1–13. https://doi.org/10.1016/j.ijis.2018.02.001

Cissé, M. (2018). Democratizing AI in Africa. *The UNESCO Courier, 3*(July-September), 20-21. https://en.unesco.org/courier/2018-3/democratizing-ai-africa

de Raadt, J. D. R., & de Raadt, V. D. (2014). *From multi-modal systems thinking to community development: Regaining our humanity through community.* Melbourne Centre for Community Development. http://www.melbourneccd.com/books/community.pdf

*Donaires, O. S., Cezarino, L. O., Caldana, A. C. F., & Liboni, L. (2018). Sustainable development goals: An analysis of outcomes. *Kybernetes, 48*(1), 183–207. https://doi.org/10.1108/K-10-2017-0401

Doucet, A., Evers, J., Guerra, E., Lopez, N., Soskil, M., & Timmers, K. (2018). *Teaching in the fourth industrial revolution: Standing at the precipice.* Routledge. https://doi.org/10.4324/9781351035866

Duraiappah, A. K. (2018). Director's message: Artificial intelligence for education. *The Blue DOT, 9*, 1. https://mgiep.unesco.org/the-blue-dot-issue-9

*Ellahi, R. M., Ali Khan, M. U., & Shah, A. (2019). Redesigning curriculum in line with Industry 4.0. *Procedia Computer Science, 151*, 699–708. https://doi.org/10.1016/j.procs.2019.04.093

*Fayomi, O. S. I., Okokpujie, I. P., Fayom, G. U., & Okolie, S. T. (2019). The challenge of Nigeria researcher in meeting up with sustainable development goal in 21st century. *Energy Procedia, 157*, 393–404. https://doi.org/10.1016/j.egypro.2018.11.204

*Fennell, S., Kaur, P., Jhunjhunwala, A., Narayanan, D., Loyola, C., Bedi, J., & Singh, Y. (2018). Examining linkages between smart villages and smart cities: Learning from rural youth accessing the internet in India. *Telecommunications Policy, 42*(10), 810–823. https://doi.org/10.1016/j.telpol.2018.06.002

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production, 252*, 1–18. https://doi.org/10.1016/j.jclepro.2019.119869

Gough, D., Oliver, S., & Thomas, J. (2012). Introducing systematic reviews. In D. Gough, S. Oliver, & J. Thomas (Eds.), *An introduction to systematic reviews* (pp. 1–16). SAGE Publications. https://uk.sagepub.com/en-gb/eur/an-introduction-to-systematic-reviews/book245742

*Grodotzki, J., Ortelt, T. R., & Tekkaya, A. E. (2018). Remote and virtual labs for Engineering Education 4.0. *Procedia Manufacturing, 26*, 1349–1360. https://doi.org/10.1016/j.promfg.2018.07.126

*Gusmão Caiado, R. G., Leal Filho, W., Quelhas, O. L. G., Luiz de Mattos Nascimento, D., & Ávila, L. V. (2018). A literature-based review on potentials and constraints in the implementation of the Sustainable Development Goals. *Journal of Cleaner Production, 198*, 1276–1288. https://doi.org/10.1016/j.jclepro.2018.07.102

*Habanik, J., Grencikova, A., & Krajco, K. (2019). The impact of new technology on sustainable development. *Engineering Economics, 30*(1), 41–49. https://doi.org/10.5755/j01.ee.30.1.20776

*Hariharasudan, A., & Kot, S. (2018). A scoping review on digital English and Education 4.0 for Industry 4.0. *Social Sciences, 7*(11), 227. https://doi.org/10.3390/socsci7110227

Hemingway, P., & Brereton, N. (2009). In Hayward Medical Group (Ed.), *What is a systematic review?* http://www.medicine.ox.ac.uk/bandolier/painres/download/whatis/syst-review.pdf

*Hidayatno, A., Destyanto, A. R., & Hulu, C. A. (2019). Industry 4.0 technology implementation impact to industrial sustainable energy in Indonesia: A model conceptualization. *Energy Procedia, 156*, 227–233. https://doi.org/10.1016/j.egypro.2018.11.133

Hodson, J. (n.d.). *Can artificial intelligence help us achieve universal quality education?* UNESCO. https://mgiep.unesco.org/article/can-artificial-intelligence-help-us-achieve-universal-quality-education

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning.* Center for Curriculum Redesign. https://curriculumredesign.org/our-work/artificial-intelligence-in-education/

*Hughes, L., Dwivedi, Y. K., Misra, S. K., Rana, N. P., Raghavan, V., & Akella, V. (2019). Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda. *International Journal of Information Management, 49*, 114–129. https://doi.org/10.1016/j.ijinfomgt.2019.02.005

*Javaid, M., & Haleem, A. (2019). Industry 4.0 applications in medical field: A brief review. Current *Medicine Research and Practice, 9*(3), 102–109. https://doi.org/10.1016/j.cmrp.2019.04.001

*Jia, M., Komeily, A., Wang, Y., & Srinivasan, R. S. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction, 101*, 111–126. https://doi.org/10.1016/j.autcon.2019.01.023

Kemato, H. (2018). How AI will change education. *The BlueDot, 9,* 25–26. https://d27gr4uvgxfbqz.cloudfront.net/files%2Fb5f1be58-9162-4a68-85d1-125bd6ecca60_The%20Blue%20Dot%209.pdf

*Kučak, D., Juričić, V., & Đambić, G. (2018). Machine learning in education — a survey of current research trends. *Annals of DAAAM & Proceedings, 29*, 406–410. https://doi.org/10.2507/29th.daaam.proceedings.059

*Lou, Y. (2018). Designing interactions to counter threats to human survival. She Ji: *The Journal of Design, Economics, and Innovation, 4*(4), 342–354. https://doi.org/10.1016/j.sheji.2018.10.001

*Luthra, S., & Mangla, S. K. (2018). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection, 117*, 168–179. https://doi.org/10.1016/j.psep.2018.04.018

*Mavrikios, D., Alexopoulos, K., Georgoulias, K., Makris, S., Michalos, G., & Chryssolouris, G. (2019). Using holograms for visualizing and interacting with educational content in a Teaching Factory. *Procedia Manufacturing, 31*, 404–410. https://doi.org/10.1016/j.promfg.2019.03.063

Mitra, S. (2014). The future of schooling: Children and learning at the edge of chaos. *Prospects, 44*, 547–558. https://doi.org/10.1007/s11125-014-9327-9

Mitra, S. (2019, September). *The future of learning* [Keynote speech]. Pan-Commonwealth Forum 9 (PCF9), Edinburgh, Scotland.

*Mourtzis, D., Boli, N., Dimitrakopoulos, G., Zygomalas, S., & Koutoupes, A. (2018). Enabling small and medium enterprises (SMEs) to improve their potential through the Teaching Factory paradigm. *Procedia Manufacturing, 23*, 183–188. https://doi.org/10.1016/j.promfg.2018.04.014

*Mourtzis, D., Vasilakopoulos, A., Zervas, E., & Boli, N. (2019). Manufacturing system design using simulation in metal industry towards Education 4.0. *Procedia Manufacturing, 31,* 155–161. https://doi.org/10.1016/j.promfg.2019.03.024

*Muhuri, P. K., Shukla, K., & Abraham, A. (2019). Industry 4.0: A bibliometric analysis and detailed overview. *Engineering Applications of Artificial Intelligence, 78*, 218–235. https://doi.org/10.1016/j.engappai.2018.11.007

Oakley, A. (2012). Foreword. In D. Gough, S. Oliver, & J. Thomas (Eds.), *An introduction to systematic reviews* (pp. vii–x). SAGE Publications. https://uk.sagepub.com/en-gb/eur/an-introduction-to-systematic-reviews/book245742

*Oberc, H., Prinz, C., Glogowski, P., Lemmerz, K., & Kuhlenkötter, B. (2019). Human robot interaction – learning how to integrate collaborative robots into manual assembly lines. *Procedia Manufacturing, 31*, 26–31. https://doi.org/10.1016/j.promfg.2019.03.005

OECD. (2019a). *Artificial intelligence in society.* OECD Publishing. https://doi.org/10.1787/eedfee77-en

OECD. (2019b). Scoping the OECD AI principles: Deliberations of the expert group on artificial intelligence at the OECD (AIGO). *OECD Digital Economy Papers, No. 291*. https://doi.org/10.1787/d62f618a-en

Pollitzer, E. (2019). Creating a better future: Four scenarios for how digital technologies could change the world. *Journal of International Affairs, 72*(1), 75–90. https://www.jstor.org/stable/26588344

Popenici, S. D., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning, 12*(22), 1–13. https://doi.org/10.1186/s41039-017-0062-8

Richardson, K. (2015). *An anthropology of robots and AI: Annihilation anxiety and machines.* Routledge.

Rizk, J. (2020). Considerations for implementing emerging technologies and innovative pedagogies in the 21st century. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 447–460). Springer.

Rosa, W. (Ed.). (2017). Transforming our world: The 2030 agenda for sustainable development. *In A new era in global health* (pp. 529-567). https://doi.org/10.1891/9780826190123.ap02

Rubin, A., & Brown, A. (2019). Unlocking the future of learning by redesigning educator learning. In J. W. Cook (Ed.), *Sustainability, human well-being, and the future of education* (pp. 235-268). Springer Nature. https://doi.org/10.1007/978-3-319-78580-6_7

Schwaninger, M. (2015). Organizing for sustainability: A cybernetic concept for sustainable renewal. *Kybernetes, 44*(6/7), 935–954. https://doi.org/10.1108/K-01-2015-0008

Smolenski, N. (2016). *Academic credentials in an era of digital decentralization.* https://www.academia.edu/29403234/Academic_Credentials_in_an_Era_of_Digital_Decentralization

*Stock, T., Obenaus, M., Kunz, S., & Kohl, H. (2018). Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Safety and Environmental Protection, 118*, 254–267. https://doi.org/10.1016/j.psep.2018.06.026

The leapfrog model: What technology can do for Africa. (2017). *The Economist, 425*(9066), 5.

UNESCO. (2019a). Artificial intelligence in education: Challenges and opportunities for sustainable development. *Working Paper on Educational Development No. 7*. https://unesdoc.unesco.org/ark:/48223/pf0000366994

UNESCO. (2019b). *Meeting commitments: Are countries on track to achieve SDG4?* https://reliefweb.int/sites/reliefweb.int/files/resources/UNESCO-2019-HLPF_UIS_Meeting-EN-v7-web_aer.pdf

UNESCO Institute for Statistics. (2016). *The world needs almost 69 million new teachers to reach the 2030 education goals.* https://unesdoc.unesco.org/ark:/48223/pf0000246124

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. https://sustainabledevelopment.un.org/post2015/transformingourworld.

Vincent-Lancrin, S., & van der Vlies, R. (2020). Trustworthy artificial intelligence (AI) in education: Promises and challenges. *OECD Education Working Paper No. 218*. https://doi.org/10.1787/a6c90fa9-en

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch S., Felländer, A., Simone Daniela Langhans, S. D., Tegmark, M., & Nerini F. F. (2020). The role of artificial intelligence in achieving the sustainable development goals. *Nature Communications, 11*, 1–10. https://doi.org/10.1038/s41467-019-14108-y

Visvizi, A. (2022). Artificial intelligence (AI) and sustainable development goals (SDGs): Exploring the Impact of AI on Politics and Society. *Sustainability, 14*(3), 1730. https://doi.org/10.3390/su14031730

*Wan Chik, W. N. A., & Arokiasamy, L. (2019). Perceived higher education climate of academics in Malaysian private institutions in Industry 4.0. *Global Business & Management Research, 11*(1), 488–504. http://www.gbmrjournal.com/pdf/vol.%2011%20no.%201/V11N1_2019.pdf

West, M., Kraut, R., & Chew, H. E. (2019*). I'd blush if I could: Closing gender divides in digital skills through education.* UNESCO Digital Library. https://unesdoc.unesco.org/ark:/48223/pf0000367416.page=7

World Economic Forum. (2017, January). *Realizing human potential in the Fourth Industrial Revolution: An agenda for leaders to shape the future of education, gender and work* [White paper]. http://www3.weforum.org/docs/WEF_EGW_Whitepaper.pdf

World Economic Forum. (2020). *Centre for the Fourth Industrial Revolution.* https://www.weforum.org/centre-for-the-fourth-industrial-revolution/

Wozniak, K. (2020). Personalized learning for adults: An emerging andragogy. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 185–198). Springer.

*Xue, L., Weng, L., & Yu, H. (2018). Addressing policy challenges in implementing sustainable development goals through an adaptive governance approach: A view from transitional China. *Sustainable Development, 26*(2), 150–158. https://doi.org/10.1002/sd.1726

*Zabidin, N. S., Belayutham, S., & Che Ibrahim, C. K. I. (2019). A bibliometric analysis of Industrial Revolution (IR) 4.0 in construction engineering education. *MATEC Web of Conferences, 266*, (Article number 05006). https://doi.org/10.1051/matecconf/201926605006

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