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Is Education 4.0 a Sufficient Innovative, and Disruptive Educational Trend to Promote Sustainable Open Education for Higher Education Institutions? A Review of Literature Trends

*Chaka Chaka**

Department of English Studies, College of Human Sciences, University of South Africa, Pretoria, South Africa

The paper explored whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for higher education institutions (HEIs). To investigate whether this is the case, the paper reviewed published journal articles that provide real-world, empirical applications of Education 4.0 in the higher education (HE) sector that are intended to promote and realize the United Nations' (UN) sustainable development goals (SDGs). In particular, the paper focused on aspects of SDGs related to education (or to sustainable open education), and which had relevance to the HE sector. Three of the findings of this review study are worth mentioning. First, real-world Education 4.0 is confined to certain countries, and is more concentrated to a few countries and to a few HEIs. Second, ten sets of Education 4.0 technologies were classified as disruptive, scalable, and sustainable, and as holding the prospect to promote sustainable open higher education in accord with the UN's SDGs. Thirdly, most of the soft-skill affordances cited (especially the twenty-first century skills cited), lend themselves well as *stylized facts* as they predate Education 4.0 and are, thus, not exclusive to it.

Keywords: higher education, Education 4.0, fourth industrial revolution, Industry 4.0, sustainable open higher education, innovation

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****Correspondence:***
Chaka Chaka
chakachaka8@gmail.com

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INTRODUCTION

During crises and human pandemics, new changes and unexpected challenges emerge, necessitating new ways of doing things. This seems to have been the case with the current novel coronavirus disease-2019 (COVID-19) pandemic. The pandemic has not only caused major sudden changes, but it has also put a halt to the old ways of doing things in different spheres of life. Education in general and, particularly, higher education (HE) has not been immune to such pandemic-induced abrupt changes and their associated challenges. Elsewhere, Chaka (2020a) refers to this rapid change scenario as episodic outbursts and massive disruptions accompanied by a series of punctuated changes. And, these punctuated changes appear to continue unabated, given the flowing and ebbing of the viral infections and the on- and off-lockdown measures across the globe. Prior to the pandemic, and more so during and post-pandemic, certain digital innovations were already being touted as possible solutions for, especially, the HE sector.

One such digital innovation is Education 4.0. Since its pre-pandemic days, Education 4.0 was already being seen as holding the prospects of being a game-changer within the HE sector. Indeed, Sharma (2019) points out that Education 4.0 will enable students to remotely access courses and register for them based on diverse open online courses, voice calling, and video chatting. In this particular setup, data will be leveraged to extrapolate courses in which students will likely to enroll in large numbers and to predict their likely future employability based on the knowledge and skill sets they possess (Salomon, 2019). As such, Education 4.0 is seen as a disruptive educational innovation capable of unbundling the HE system in favor of repackaged, personalized, and peer-to-peer learning offerings (Fisk, 2017). In this instance, the disruptive nature of Education 4.0 and its game-changing capability serve as one of its main differentiators. This relates, primarily, to reconfiguring the HE system, disaggregating its course offerings, and the kinds of technologies through which students are to access its course offerings and interact with those course offerings. This means that Education 4.0 also represents an educational and innovative disruptor. At one point, information technology (IT) was touted as a game-changer (Oblinger, 2012) and as an educational and innovative disruptor, too.

Against this background, a case can be made that Education 4.0 is what open and inclusive higher education needs in order for different nations to be able to achieve the United Nations' sustainable development goals (SDGs). But not only that, rather, the rupturing effects of the COVID-19 pandemic require a rethinking of how HE is offered. Therefore, this paper set out to explore whether Education 4.0 is a sufficient innovative, and disruptive educational development to promote sustainable open education for higher education institutions (HEIs). To do so, it reviewed published journal articles that provided real-world, empirical applications of instances of Education 4.0 in the HE sector that were intended to promote and realize the UN's SDGs (Ally and Wark, 2020; Bai et al., 2020; Zizka and Varga, 2020). The review took into account that Education 4.0 is a broad, overarching concept that is informed by the Fourth Industrial Revolution (4IR) (Chaka, 2020b). It also considered its variation such as Higher Education 4.0 and cognate technologies related to 4IR such as artificial intelligence (AI), automation, robotics, blockchain, big data, cloud computing, augmented reality (AR), virtual reality (VR), and the Internet of Things (IoT) (Ally and Wark, 2020; Chaka, 2020b), as long as they had a specific relation and a direct application to Education 4.0 and sustainable open education, or SDGs.

SITUATING EDUCATION 4.0 AND INNOVATION

There are different types of HEIs. Conventionally, the two main types of HEIs are traditional universities (either research-intensive or non-research-intensive universities) and universities of applied sciences (cf. Andreadakis and Maassen, 2019a). Mostly, the typology of HEIs varies according to countries in which HEIs are situated. For instance, some countries have a more nuanced differentiation between their HEIs. Classic examples are technical/technological HEIs, medical universities, business and management sciences HEIs, pedagogical HEIs, and theological HEIs (see Eurydice, 2021). So, this HE landscape typology is important to note.

Since this paper's main focus is on HE, its use of Education 4.0 is solely restricted to this sector, notwithstanding the fact that this term often has a generic application. That is, Education 4.0 is used to embody the same meaning as Higher Education 4.0 or University 4.0. The paper posits that Education 4.0 is an educational derivative of the Fourth Industrial Revolution (4IR). In this sense, it is informed and underpinned by the same cognate and flagship technologies as those attributed to 4IR. Some of these technologies are: autonomous robots; artificial intelligence (AI); cloud computing; quantum computing; big data; smart sensors; virtual reality (VR); augmented reality (AR); the Internet of Things (IoT); or Industrial Internet of Things (IIoT); simulation; additive manufacturing; 3D printing; holograms; and drones (Keser and Semerci, 2019; Reaves, 2019; Salomon, 2019; Sharma, 2019; Bongomin et al., 2020; Butt et al., 2020; Chaka, 2020b, 2021). A digital fusion and embedding of these cluster technologies within a cyber-physical system (CPS) is a key differentiating factor of this 4.0 technological development. Two of Education 4.0's variants, or two of its equivalents within the HE landscape are Higher Education 4.0 (Chea and Huan, 2019; Sharma, 2019; Goh and Abdul-Wahab, 2020; Adnan et al., 2021) and University 4.0 (Gueye and Exposito, 2020). In addition, on a comparative basis, Education 4.0 is an advanced version of its preceding iterations such as Education 1.0, Education 2.0, and Education 3.0 in the same way as 4IR is an advanced iteration of its predecessor technologies in the form of Industrial Revolution 1.0, Industrial Revolution 2.0 and Industrial Revolution 3.0, and Industry 1.0, Industry 2.0 and Industry 3.0, respectively (Chea and Huan, 2019; Sharma, 2019; Butt et al., 2020; Chaka, 2020b; Miranda et al., 2021). Another similarity is that of Web 4.0 when it is compared to Web 1.0, Web 2.0, and Web 3.0 (Keser and Semerci, 2019; Salomon, 2019).

In this context, Education 1.0, 2.0, 3.0, and 4.0 can each be seen as a download education, an open-access education, a knowledge-producing education, and an innovation-producing education (Himmetoglu et al., 2020)., respectively. For her part, Sharma (2019) points out that these four versions of education each represents: the era of memorization; the dawn of Internet-powered education; the era of education as consumption; and the advent of a change-driven education. Butt et al. (2020) characterize each of these four iterations as corresponding to: a one-way, passive educational process (Education 1.0); a collaborative education with passive and active learning (Education 2.0); an open, collaborative, flexible, and creative education (Education 3.0); and an education marked by a dynamic, independent, active, innovative, and self-directed learning (Education 4.0).

Notwithstanding the differing definitions attached to these four codes of education, what is clear is that the last iteration (Education 4.0) is conceptually, radically different from its three other counterparts. In light of the preceding characterization of Education 4.0, for this paper, Education 4.0 is, especially in the HE sector, an education that leverages and is powered by all of the currently available 4IR technologies including the relevant future technologies as long as they are classified under the 4IR code name. In this instance, the paper proposes three types of Education 4.0: a fully integrated Education 4.0, a near-fully integrated Education 4.0, and a partial Education 4.0. The first is as described in the preceding sentence; the second entails the use of a number of different Education 4.0 technologies, but not all of them; and the third incorporates the use of one to three different Education 4.0 technologies. This distinction is critical as Education 4.0 is, at times, like 4IR, vaguely constructed. Overall, whatever type it is and whatever permutation it assumes, Education 4.0 is about integrating and leveraging these technologies for educational purposes (Gueye and Exposito, 2020).

Core Features of Education 4.0

Education 4.0 comprise certain core features. These features include:

- Integration and fusion of various digital technologies (e.g., the 4IR technologies mentioned above and others not cited above) and mobile technologies
- Flipped classrooms, massive open online courses (MOOCs), social network-based learning, smart campuses, seamless learning environments, and open educational resources (OERs)
- Open and distance learning, open access, lifelong learning, application-oriented learning, adaptive learning, individualized learning, and self-paced learning (Himmetoglu et al., 2020).

Most of these features such as those listed in the last two bullets, bar smart campuses, are not new, though. That is, they do not owe their origin to 4IR/Industry 4.0 nor did they come into existence due to 4IR/Industry 4.0. It is their incorporation into the 4IR/Industry 4.0 paradigm that makes them eligible features for Education 4.0. Importantly, it is the digitization and automation, and the integration and harnessing of human and technological capabilities within the physical, digital, and biological spaces of education that spawn Education 4.0. Concerning the HE sector, this development results in Higher Education 4.0 or University 4.0.

Innovation

As a concept, innovation predates the advent of Education 4.0. For example, throughout human history, innovation has permeated different spheres of life in sector-specific ways. The same is true of education as a sector with multiple layers. Elsewhere, Serdyukov (2017) maintains that innovation entails developing a novel idea, a change, and a disruption. To this effect and narrowly, there is educational innovation or technological innovation. Serdyukov (2017) also argues that innovation is revolutionary or evolutionary (also see Osolind, 2012), and disruptive or sustaining (also see Yu and Hang, 2010; Christensen et al., 2018; Kylliäinen, 2019). Revolutionary innovation leads to a wholesale change, resulting in a complete replacement of the old system with the new one; evolutionary innovation is about incremental improvements, and ensures continuity. Disruptive innovation leads to a radical change of the whole system, while sustaining innovation preserves the current *status quo* (Serdyukov, 2017). The paper contends that Education 4.0 can assume any of these four permutations in terms of its innovativeness. Moreover, the innovative form that Education 4. 0 assumes is likely to determine whether it is sustainable, disruptive, and scalable or not, and whether it can lead to sustainable open higher education in line with the UN's SDGs or not.

PURPOSE OF THE STUDY

The purpose of this study was to explore whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for HEIs. To investigate whether this was the case, the paper reviewed sixteen published journal articles that documented real-world, empirical applications of Education 4.0 in the HE sector that were intended to promote and realize the UN's sustainable development goals (SDGs) (Ally and Wark, 2020; Zizka and Varga, 2020; de S Oliveira and de Souza, 2022). In particular, the study focused on elements related to either education for sustainable development (ESD) (Cebrián and Junyent, 2015; Andreadakis and Maassen, 2019b) or education or sustainable open HE, and which had relevance to the HE sector. Based on this, the study had the following research questions (RQs):

- RQ1: Which HEIs are reported to apply Education 4.0, in which countries are they situated, and who are the reported participants?
- Which types of Education 4.0 technologies do these HEIs apply as reported by the reviewed articles?
- RQ2: What are the affordances offered by the utilized Education 4.0 technologies?
- RQ3: What innovation classification does this Education 4.0 fall under?
- RQ4: What academic disciplines or subject areas is it applied to?
- RQ5: Does the reported Education 4.0 have a sustainable open higher education element and focus on the UN's sustainable development goals (SDGs)?

METHODS

Search Strategy and Full-Text Downloading

A literature search strategy for eligible and relevant articles was carried out online from June 2021 to October 2021. It entailed determining and locating suitable bibliographic databases. Thirteen online databases, which included two search engines, were identified. These were: Google; Bing; Education Resource Information Center (ERIC); IEEE Xplore; ScienceDirect; Scopus; SpringerLink; Taylor & Francis Online; Wiley Online Library; Emerald Insight; Sematic Scholar; Google Scholar; and Microsoft

Academic (**Figure 1**). Keywords, in search string combinations, were developed and iteratively queried into these databases according to their bespoke requirements. Some of these search string combinations were as follows:

- "Education 4.0" AND "technologies for sustainable development in higher education"
- "Education 4.0 technologies" AND "sustainable development goals in higher education"
- "Education 4.0" AND "technologies for sustainable open education in higher education"
- "Education 4.0" AND "sustainable development goals" AND sustainable open education AND technologies
- "Education 4.0" AND "sustainable* open education" in higher education

Education 4.0 was varied or swapped with Industry 4.0 and Higher Education 4.0, and with any of the 4IR technologies. Quotation marks were employed to ensure that entire phrases are located within a document; *AND* was used to identify groups of keyword phrases available in a document; and the asterisk (*) was employed to ensure that all possible suffixes for a word were locatable within a document

All qualifying full-text articles that were located in the above-mentioned databases and search engines were downloaded. They were, then, saved in thirteen separate folders named according to

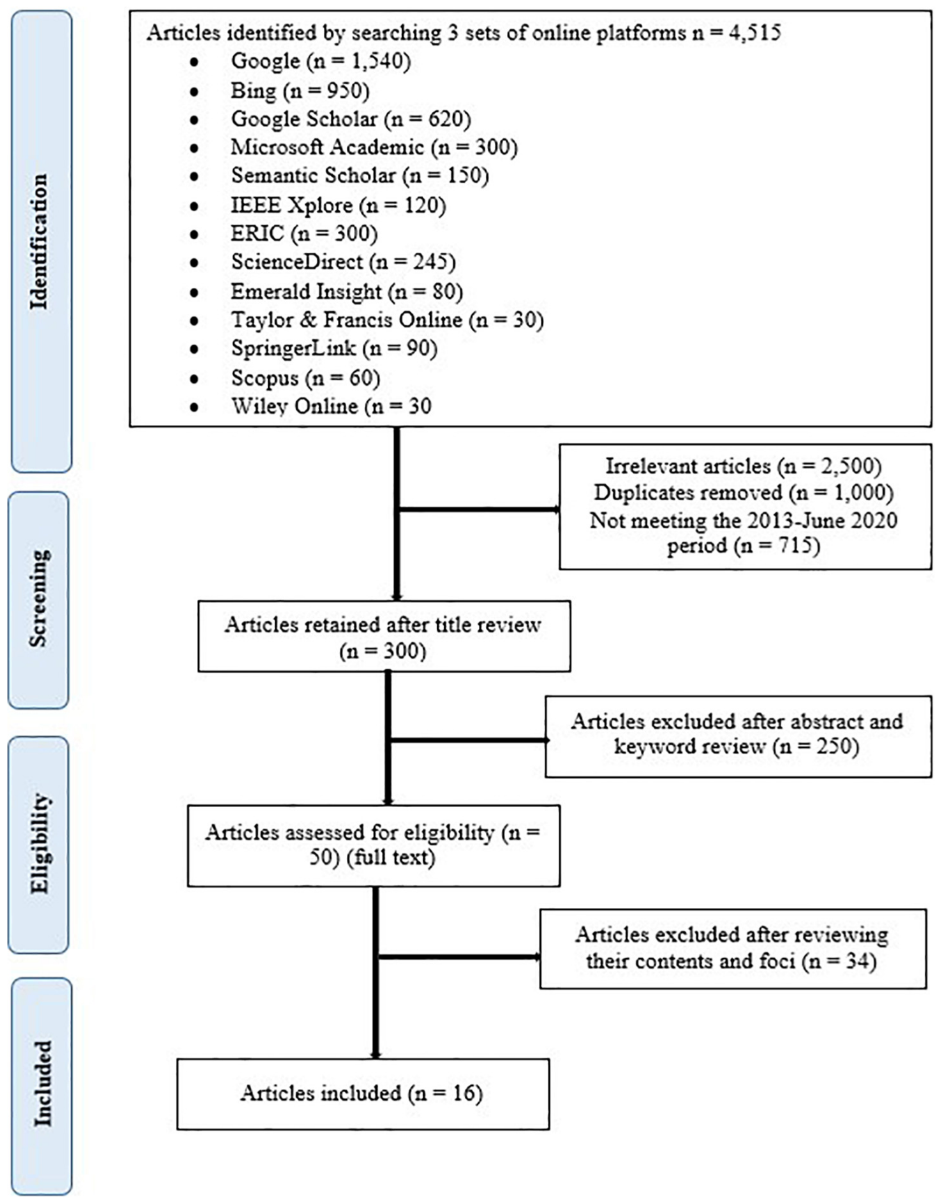

FIGURE 1 | The PRISMA flow chart and the online search platforms.

the names of the databases and search engines from which they were downloaded. These folders were archived in File Explorer. The total number of the full-text articles saved in these folders was 300 (see **Figure 1**).

If there are journal articles that focus on real-world, empirical applications of Education 4.0 together with its related technologies in the HE sector and that deal with an element of sustainable open higher education or with UN's SDGs as highlighted in this paper, but which do not explicitly mention Education 4.0 as one of their keywords as indicated in the search string combinations provided above, then, they could have been missed by the search strategy employed here. However, the possibility of this happening and of the *bubble effect*—a selection bias—(see Piasecki et al., 2018) is mitigated by the fact that most of the aggregating algorithms used by the thirteen online databases are intelligent enough to locate such journal articles. Additionally, the use of these different online databases compensates for one another's weaknesses. This is particularly the case when different search engines and different online bibliographic databases are employed together for search purposes. For example, Piasecki et al. (2018) point out that even though Google Search and Google Scholar have drawbacks, they, nevertheless, are appropriate for certain forms of qualitative systematic reviews when used together.

Eligibility Criteria and Selection of Studies

Even though this was a literature review paper, it employed aspects of a systematic literature review (SLR) in its research design, or what Snyder (2019) calls semi-systematic review. It also utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) in its search strategies. Based on this, the study had eligibility (inclusion) criteria, examples of which included the following:

- Articles published between 2015 and October 2021
- Articles published in peer-reviewed journals and published in internationally accredited conference proceedings (e.g., IEEE and Procedia)
- Articles that simultaneously focused on Education 4.0 (and its variations, e.g., Industiry4.0 or/Industrie 4.0) and elements of sustainable open education in higher education/elements of SDGs in higher education
- Articles that provided real-world instances/cases of the implementation of Education 4.0 in given higher education institutions involving students
- Articles that did not report pure prototypes or pure prototype implementations
- Articles that were not pure reviews/not pure theoretical or conceptual reflections of Education 4.0
- Articles published in English

The year 2015 was used as a starting point because it is the year in which the UN declared its SDGs (Ally and Wark, 2020; Zizka and Varga, 2020). A four-phase selection process was conducted for identifying, choosing, and screening qualifying articles. This process was based on the PRISMA flowchart (**Figure 1**). The RISMA approach has transparency and clarity as one of key features (Liberati et al., 2009; Moher et al., 2009). In the first phase, articles were searched and identified each time search string combinations had been queried in each of the 13 online bibliographic databases. Collectively, 4,515 articles were returned by this phase. This phase was followed by the second one in which the 4,515 returned articles were screened. The screening involved reviewing the titles and abstracts of these articles. After conducting this process, 300 articles were retained, while 4,215 were eliminated for irrelevance and for being duplicates. During the third phase, the remaining 300 articles were reviewed in terms of their abstracts. This process resulted in 250 articles being excluded due to duplicates and irrelevance. In the fourth phase, only 16 articles were retained as their contents and foci satisfied the eligibility criteria mentioned above. These 16 articles were the major data source from which the data sets of the current study were extracted.

Data Extraction, Coding and Inter-Rater Reliability

Data sets, which were informed by twelve article characteristics, were extracted from the 42 full-text articles mentioned earlier. These characteristics were: author(s); country; year of publication; name of HEI; participants; a fully integrated Education 4.0, a near-fully integrated Education4.0, or a partially integrated Education 4.0; types of Education 4.0 technologies used; affordances offered by Education 4.0 technologies used; innovation classification; academic disciple(s)/subject area(s); a sustainable open HE element; and SDGs (also see the RQs of this study). A coding scheme based on these twelve characteristics was developed. The researcher and two independent coders extracted the data sets from the 16 articles using this coding scheme. To maintain data extraction and data coding consistency, interrater reliability (IRR) as recommended by Landis and Koch (1977) and Belur et al. (2018) was used. For instance, Landis and Koch (1977) offer the following range of the kappa (κ) scores and their interpretation for IRR: 0.81–1.00 = near perfect; 0.61–0.80 = substantial; 0.41–0.60 = moderate; 0.21–0.40 = fair; 0.00–0.20 = slight; $<$ 0 = poor. The IRR of the three coders was 0.80, which was substantial.

Data Analysis

Data sets were analyzed using quantitative content analysis and qualitative content analysis (Vaismoradi et al., 2013; Vaismoradi and Snelgrove, 2019). First, quantitative content analysis involved calculating frequencies of occurrence of the twelve article characteristics mentioned above. Second, qualitative content analysis entailed analyzing themes formulated from the twelve article characteristics. Thereafter, themes emerging from these characteristics were iteratively compared with a view to synthesizing them. This means that for each full-text article, firstly, the author(s), the country of origin of the author(s), the year of publication, the name of an HEI involved, and the participants mentioned were identified. Secondly, each full-text article was evaluated on whether the type of Education 4.0 it mentioned was fully, near-fully, or partially integrated as

TABLE 1 | Authors' countries of origin, years of publication, HEIs, participants, and academic disciplines/subjects.

Article number	References	Country of origin	HEIs	No. of participants	Academic disciplines/subjects
Art. 1:	Elbestawi et al., 2018	Canada	McMaster University	N/M	Engineering and technology
Art. 2:	Adnan et al., 2019	Malaysia	Three Malaysian public universities	19 English language educators	English language
Art. 3	Adnan et al., 2020	Malaysia	Universiti Teknologi MARA Perak Branch	560 undergraduate students	English as a second language, Mandarin & Arabic
Art. 4	Prieto et al., 2019	Spain	Universitat Politècnica de Catalunya	Undergraduate and graduate students	Industrial, aerospace and audiovisual engineering
Art. 5	Bonfield et al., 2020	Australia, Singapore, UK, and Ireland	Deakin University, Nanyang Technological University (NTU) & University of Bath	Deakin = Campus users; NTU = Singaporeans of all ages; Bath = N/M	NTU: aerospace, data analytics, robotics and predictive analysis
Art. 6	Bushmeleva et al., 2020	Russian Federation	Vyatka State University	79 third-year students	Informatics, mathematics and physics
Art. 7	Ciolacu et al., 2020	Germany	Deggendorf Institute of Technology	4 computer science students	Mathematics and knowledge management
Art. 8	dos Silva et al., 2020	Brazil	Federal University of Paraná	32 undergraduate and graduate students	Mobile robotics
Art. 9	Silva et al., 2020	Brazil	Federal University of Paraná	6 education professionals	Teacher education
Art. 10	Yoshino et al., 2020	Brazil	Universidade Tecnológica Federal do Paraná	111 university students	Science, technology, engineering, and math; computer science; and teaching courses
Art. 11	Marcial, 2020	Philippines	Silliman University	Students and community	Technology business
Art. 12	Porubčinová et al., 2020	Slovakia	Slovak University of Technology in Bratislava	P.hD. Students and teachers	Civil engineering and materials science and technology
Art. 13	Benis et al., 2020	Israel	Holon Institute of Technology	N/M	Industrial engineering and technology management
Art. 14	López et al., 2021	Mexico	Tecnologico de Monterrey	Undergraduate mechanical engineering students	Mechanical engineering
Art. 15	Miranda et al., 2021	Mexico	Tecnologico de Monterrey	40 to 60 undergraduate students	Computer science
Art. 16	de S Oliveira and de Souza, 2022*	Brazil	Federal Rural University of Pernambuco	13 undergraduate students	Computer science

*HEIs, higher education institutions; N/M, not mentioned. *Even though this article's indicated publication date is 2022, its journal copyright date is 2021.*

explained earlier. Thirdly, each full-text article was evaluated in terms of the types of Education 4.0 technologies used in it, the affordances provided by those technologies, and the innovation classification of those technologies. The innovation classification related to revolutionary, evolutionary, or disruptive innovation as discussed earlier (see Osolind, 2012; Serdyukov, 2017; Christensen et al., 2018; Kylliäinen, 2019). Fourthly and lastly, each full-text article was assessed according to the academic disciples it mentioned, the sustainable open HE element it had, and its reference to an SDG.

All of these descriptors informed the findings presented below. Moreover, in the discussion of the findings, these descriptors in the form of themes have been synthesized by drawing both similarities and differences.

FINDINGS

The findings presented in this section are grounded on the data sets extracted from the 16 articles reviewed in this paper and are structured according to the manner in which these data sets have been codified, categorized, and analyzed as described above. Additionally, these findings have been framed in line with the twelve articles' characteristics investigated in this paper, and in response to the six research questions (RQs) posed in this paper.

Authors' Countries of Origin, Years of Publication, Higher Education Institutions, Participants, and Academic Disciplines/Subjects

As illustrated in **Table 1**, all together, these articles were written by authors from fourteen countries. Except for one article, all the other articles were co-authored. Four articles are from Brazil, and two articles are from Malaysia and Mexico, respectively. While the remaining articles are from a single country each, one article represents four countries. Nine of the reviewed articles were published in 2020, whereas three of them were published in 2021. In all, the reviewed articles mentioned 20 HIEs. Two articles mentioned three HEIs each, with one of them having not specified the names of its three HEIs. Of the seventeen HEIs specified by their names, two of them, Federal University of Paraná (Brazil) and Tecnologico de Monterrey (Mexico) feature twice in the reviewed articles. Additionally, of the seventeen specified HEIs, ten are universities of applied sciences, while seven are traditional universities.

FIGURE 2 | Articles and Education 4.0 technologies used. N/A, not applicable; N/M, not mentioned; SO HE, sustainable open higher education; SDGs, sustainable development goals.

Barring two HEIs (Art. 1 and Art. 13) and save for one of the three collective HEIs (Art. 5), all the other reviewed articles mentioned their participants. All of these participants were mainly university students, except for one cohort that comprised both students and the community and another cohort that consisted of participants of all ages. Seven articles provided the exact number of the participants involved in in their Education 4.0 activities, with one article providing an approximate number only. The overall number of the specified participants is 824. The other articles did not specify the number of the participants involved in their Education 4.0 activities.

Pertaining to academic disciplines/subjects, all the articles specified their respective academic disciplines/subjects involved in Education 4.0 initiatives. While some of the articles stated a combination of academic disciplines and academic subjects, others mentioned specific academic subjects such as English language, Mandarin, and mathematics. The most cited overall academic discipline is engineering, and is followed by computer science.

Education 4.0 Technologies, Types of Education 4.0, Innovation Classification, Sustainable Open HE Elements, and Sustainable Development Goals

As depicted in **Figure 2**, apart from two articles (Art. 9 and Art. 14), all the other articles have offered the specific names of the technologies used in their Education 4.0 projects. Of these, one article (Art. 5) has provided eight specific names of its Education 4.0 technologies, while two articles (Art. 10 and Art. 12) have mentioned nine and ten specific names of their respective Education 4.0 technologies. By contrast, two articles (Art. 2 and Art. 3) have cited two specific Education 4.0 technologies each, and two other articles (Art. 11 and Art. 15) have cited one specific Education 4.0 technology apiece. The most cited Education 4.0 technologies are robots (robotics) (n = 8), including an AI-powered chatbot. They are followed by automation (n = 6), IIoT (n = 5), and 3D technology (n = 5), with IoT (n = 4), simulation (n = 4), and CPS (= 4) closely trailing these three sets of Education 4.0 technologies.

Of all the Education 4.0 technologies mentioned, the ones cited by four articles are fully integrated, and those cited by two articles are near-fully integrated. The other Education 4.0 technologies mentioned by the remaining ten articles are partially integrated. Ten sets of Education 4.0 technologies mentioned by ten articles have been classified as a disruptive innovation, whereas five sets of technologies have been categorized as an evolutionary innovation and one set of technologies has been identified as a sustaining innovation.

Eleven articles did not mention whether their Education 4.0 had any element of sustainable open higher education, or whether it lent itself to such a type of education. The remaining five articles hinted at the sustainability of their either open teaching and learning, open higher education, open approach, or open innovation. Similarly, nine articles did not mention whether their Education 4.0 had any sustainable development goals (SDGs). On the other hand, the remaining articles stated the following regarding their Education 4.0 vis-à-vis SDGs: open source; sustainable development; sustainable education; sustainable teaching and learning; sustainable manufacturing; and sustainable infrastructure.

Education 4.0 Technology Affordances

All the 16 articles have provided the affordances offered by their respective Education 4.0 technologies (**Table 2**). Depending on the number of technologies used in each instance, the affordances stated are few as in Art. 2, Art. 3, Art. 7, Art. 9, Art. 10, and Art. 14, or many as exemplified by Art. 4, Art. 6, Art. 13, Art. 15, and Art. 16. Some of the affordances provided are more detailed than others as is the case with Art. 2, Art. 8, Art. 15, Art. 16. Mainly, the hard-skill affordances mentioned by these sixteen articles are technology-specific or technology-responsive.

DISCUSSION

This part discusses the findings as presented in the previous section. Additionally, this part responds to the twelve articles' characteristics investigated in this paper and to the six research questions (RQs) of this paper. On this basis, the purpose of this study was to explore whether Education 4.0 is a sufficient innovative, and disruptive educational trend to promote sustainable open education for HEIs. As pointed out in the previous section, of the seventeen HEIs specified by their names, ten were universities of applied sciences, while seven were traditional universities. Three countries had the larger share of the reviewed articles, with one country (Brazil) having the largest share of the articles, overall. These three countries also had the most authors of the reviewed articles, with a single country (Brazil), again, having the largest share of the authors of these articles. Similarly, of the HEIs featuring in the reviewed articles, the most were from the same three countries. In this instance, two HEIs from two countries each—Federal University of Paraná (Brazil) and Tecnologico de Monterrey (Mexico)—featured twice in the reviewed articles, more than is the case with the other HEIs. To this effect, mere Google and Bing searches of the two HEIs using the string searches, Federal University of Paraná—Education 4.0 and Tecnologico de Monterrey—Education 4.0, returned 444,000 (Google)/7,500,000 (Bing) and 732,000 (Google)/252,000 (Bing) results for each of these two HEIs, respectively, at the time of writing this paper (**Figure 3**). While these search results may reflect different variables related to these two HEIs, they nonetheless illustrate the high rate of Education 4.0 instances associated with these two HEIs. Another factor here is that most articles ($n = 9$) were written in 2020 than in any other years in which these reviewed articles were published.

The majority of the participants mentioned are university students, especially undergraduate students. However, two articles mentioned composite participants: students and community members, and all-age participants. What can be extrapolated from this participant composition is that in the reviewed articles, Education 4.0 largely involved undergraduate students even though in two cases it involved both students and the general public. Slightly fewer articles provided the exact number of the participants that took part in their Education 4.0 initiatives. Collectively, these participants totaled 824. This means that the exact number of participants involved in the Education 4.0 activities not mentioned by many articles ($n = 9$) remains unknown.

With reference to academic disciplines/subjects, all the reviewed articles stated the academic disciplines/subjects that were involved in their respective Education 4.0 projects. Some of the articles provided a combination of general academic disciplines and academic subjects, while others stated specific academic subjects, of which English language, Mandarin, and mathematics are examples. This implies that some of the Education 4.0 initiatives mentioned by the reviewed articles occurred within specific, micro-academic subject areas (or within a given module), whereas others took place within generic or macro-academic disciplines. Of these generic academic disciplines, engineering is the most frequently cited, followed by computer science. This development serves as the basis to argue that in this context, engineering is leading the pioneering of Education 4.0 initiatives and seems to be experimenting more with Education 4.0 than is the case with other academic disciplines. Following it closely in this regard is computer science (see Bongomin et al., 2020; cf. Chaka, 2020b, 2021).

As highlighted in the previous section, barring two articles, all the other articles mentioned the specific names of the technologies utilized in their Education 4.0 projects. These ranged from robots, automation, and simulation to IoT, IIoT, and CPS to AI, AR, VR and sensors to 3D technologies. In addition, there were big data and cloud computing (cf. Bongomin et al., 2020; Chaka, 2021). Four sets of Education 4.0 technologies cited by four articles were identified as fully integrated, while two sets of technologies were distinguished as near-fully integrated. The rest of the other sets of Education 4.0 technologies were identified as partially integrated. This identification is based on the three types of Education 4.0 proposed earlier by this paper. This particular identification is as follows: a fully integrated Education 4.0 uses many or all of the Education 4.0 technologies; a near-fully integrated Education 4.0 entails the use of a number of different Education 4.0 technologies but not all of them; and a partially integrated Education 4.0 incorporates the use of one to three different Education 4.0 technologies. When deployed as fully integrated or as near-fully integrated Education 4.0 technologies, these technologies have the potential to make Education 4.0 a sufficient innovative, and disruptive educational trend that promotes sustainable open education for HEIs.

Ten sets of Education 4.0 technologies cited by ten articles were classified as a disruptive innovation, or as disruptive Education 4.0 technologies, while five sets were categorized as evolutionary in their innovation. One set was found to have a sustaining innovation. This classification borrows from Serdyukov (2017) categorization of innovation as described earlier, and is used here to refer to the educational innovation associated with the Education 4.0 technologies cited by the

TABLE 2 | Articles and the affordances offered by their Education 4.0 technologies.

Article number	Education 4.0 technology affordances	Article number	Education 4.0 technology affordances
Art. 1:	Offering new technical skills that emphasize the inherent multidisciplinary nature of smart systems and advanced manufacturing; addressing the educational, research, and training components of the SEPT CPS Learning Centre.	Art. 13:	Equipping students with the fundamental tools for designing, implementing, and managing automated production environments and their computerized control systems.
Art. 2:	Simulating, recording, and sharing business and professional English interactions with students; and chatting about 1,001 items related to English using the chatbot.		Smart use of the production plant and end-business mobile asset tracking technologies [e.g., bar-codes, Quick Response (QR) codes, near field communication (NFC), and radio frequency identification (RFID)].
Art. 3:	Playback immersive "real life" contents; post-processing contents into VR experiences; learner-driven learning for English as a second language, Mandarin Chinese, and Arabic learners.		Enabling fast adoption of the robot tool (Dobot Magician), and experimenting with its behaviors and constraints.
Art. 4:	Facilitating active learning and enabling students acquire Engineering Education 4.0 competences; digitalization and automation of the industrial processes; deployment of connected devices able to identify each other with computing and communication capabilities to turn them into intelligent objects with informative and self-decision making purposes; and allowing students to design and implement its own operational functionalities.		Allowing students to study in-depth some critical components of the 4IR and the IoT.
Art. 5:	**Deakin:** Using cutting-edge digital technologies to digitize Deakin's physical campus environments so as to provide campus users with a smart, personalized, responsive, and enriched campus experience (embedding emerging technologies within the physical environment, combining these with organizational vision and values and placing the Campus User at the center of the experience).		Enabling students to examine a series of business problems during the course and to solve them with BI tools such as Microsoft Power BI.
	NTU: Delivering bite-size modules directly related to Industry 4.0; developing skills and knowledge across a wide range of subjects that are closely aligned to future jobs and skills.	Art. 14:	Fostering disciplinary and transversal skills.
	Bath: FutureLearn course offerings.		**Disciplinary skills:** knowledge, attitudes, values, and skills necessary for professional practice.
Art. 6:	Fostering engineering thinking, innovative thinking, and technical thinking.		**Transversal skills:** training experiences in entrepreneurship, leadership, innovation, linking academia and the productive sector.
	NB: Students were able to systematize the necessary conceptual apparatus, studied various functional capabilities of software environments and 3D printing devices, and got the opportunity to solve specific practical and socially significant problems of the future, while showing independence in choosing 3D tools, methods of cognition.	Art. 15:	Using a decision-making lab to support students' visual analysis to solve a transportation problem in Mexico City. Encouraging entrepreneurship in higher education through the sensing, smart and sustainable enterprise creation bootcamp. Fostering multidisciplinary research in higher education through the computing intelligence, mechatronics, and Biodesign Laboratory.
Art. 7:	Networking students and their wearable devices with the Learning Management System (LMS), and classifying this learning environment as an Internet of Things (IoT).	Art. 16:	Discovering the challenge; deepening the understanding; generating and refining ideas, generating and refining ideas; and prototyping ideas.
Art. 8:	(a) Promoting 21st century skills such as (1) creativity and innovation, (2) problem-solving, (3) communication, (4) teamwork, (5) learning to learn, and (6) organization. (b) Humanoid robot 3D football simulator—enabling students to develop heuristics in the base code so that they could add new robotic skill sets such as scoring barriers, attack strategies, and goal-kick defense.		**Organizational affordances:** Developing Education 4.0 strategies; developing, updating and adapting curriculum; and improving educational experience using digital technologies.
Art. 9:	Promoting twenty-first century skills and competencies in the context of Education 4.0.		**Digital teaching affordances:** constant feedback; use of needs-based technology; and use of innovative assessment methods.
Art. 10:	Enabling students to build prototypes; and facilitating proactivity, problem-solving ability, teamwork, and leadership.		**Soft skills:** communication; social and cultural awareness; creativity; empathy; critical and analytical thinking; responsibility; problem-solving; and teamwork.
Art. 12:	Supporting the transfer of progressive technologies, collaboration in knowledge triangle (research-education-innovation) to improve know-how, innovations, and knowledge. Optimizing production, and predicting and minimizing errors from the production line.		**Hard skills:** digital technology design; technological resource management; and computational thinking.
			Pedagogical affordances: innovation approach; action-oriented learning; and blended learning.

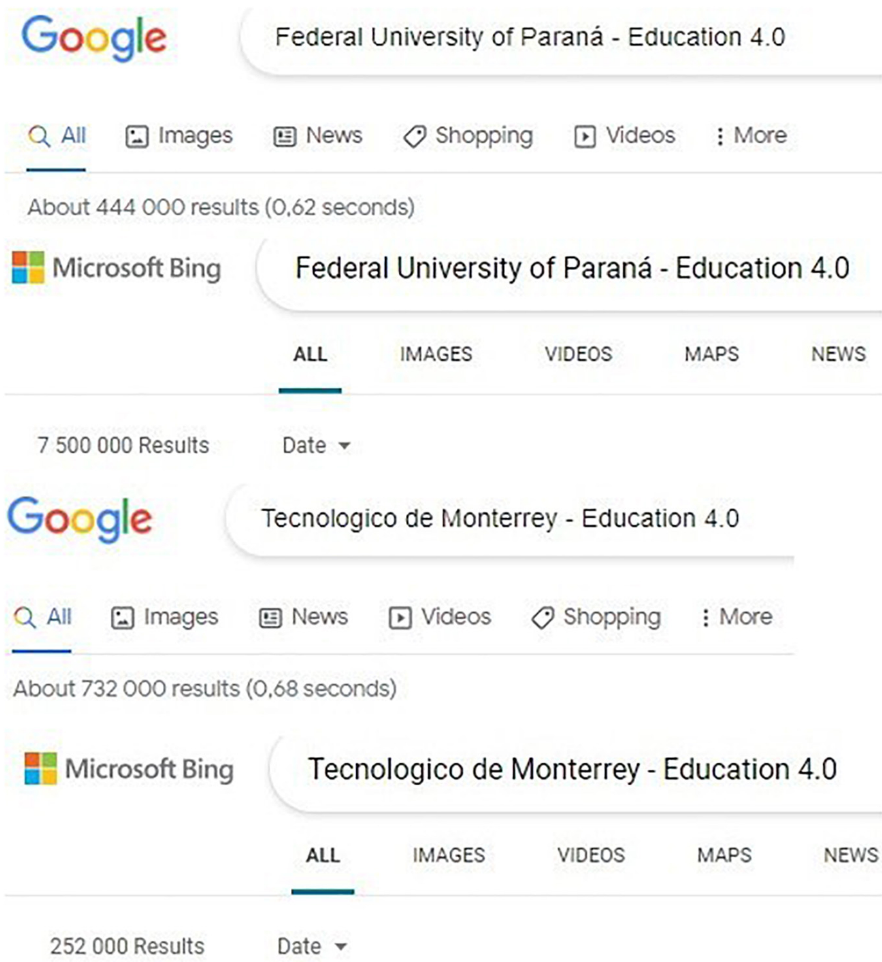

FIGURE 3 | Google and Bing search results for two HEIs.

reviewed articles. Those sets of technologies that have been categorized as disruptive or as having a disruptive innovation are scalable and sustainable. As such, based on this classificatory criterion, these types of Education 4.0 technologies have the prospect of promoting sustainable open higher education in line with the UN's sustainable development goals (SDGs) (see Cebrián and Junyent, 2015; Ally and Wark, 2020; Zizka and Varga, 2020; de S Oliveira and de Souza, 2022). As mentioned earlier, overall, five articles hinted at their open teaching and learning, their open higher education, their open approach, and their open innovation being sustainable. In terms of SDGs, seven articles characterized their Education 4.0 as either sustainable education/sustainable teaching and learning, open source, sustainable development, sustainable manufacturing, or sustainable infrastructure. As argued above, for any Education 4.0 in the HE sector to be open and sustainable, its Education 4.0 technologies must be fully or near-fully integrated, disruptive, and scalable. Only in this way and format can it be regarded as sufficiently innovative.

Finally, all the reviewed articles provided the affordances associated with their respective Education 4.0 technologies. Some of these affordances were specific and detailed, whereas others were general and non-specific. The examples of the former are "chatting about 1,001 items related to English using the chatbot" (Art. 2), " enabling students to develop heuristics in the base code so that they could add new robotic skill sets such as scoring barriers . . . and goal-kick defense" (Art. 8), and " critical and analytical thinking . . . problem-solving" (Art. 16). Instances of the latter are "facilitating active learning and enabling students acquire Engineering Education 4.0 competences (Art. 4) and "equipping students with the fundamental tools for managing automated production environments and their computerized control systems" (Art. 13). In addition, the hard-skill Education 4.0 technology affordances referenced by the reviewed articles are mainly technology-specific or technology-responsive. This means that they are technology-bound, or can only occur with the cited Education 4.0 technologies.

Moreover, most of the soft-skill affordances such as communication skills, social and cultural awareness skills, critical and analytical thinking skills, creativity, problem-solving skills, innovation, empathy, responsibility, teamwork, and leadership skills referenced by some of the reviewed articles are twenty-first century skills that predate the Education 4.0 era.

As such, they are not exclusive to Education 4.0 nor to 4IR/Industry 4.0. Elsewhere, Chaka (2020b, p. 372) refers to soft skills or twenty-first century skills "as *stylized facts* for 4IR." He borrows the phrase *stylized facts* from Helfat (2007) work in which it means widely accepted observations or empirical truths (also see Gomes et al., 2015; Hirschman, 2016). Even in this paper, the soft-skill affordances attributable to the Education 4.0 technologies mentioned by the reviewed articles lend themselves well as stylized facts as they do not need Education 4.0 technologies for them to be acquired by students.

CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

Firstly, in the context of the reviewed articles, it appears that real-world Education 4.0 is confined to certain countries, and is more concentrated to a few countries and to a few HEIs. These countries, together with their respective HEIs, are geographically confined to South America. This is so notwithstanding the fact that the search strings employed in this paper were not country- or HEI-specific. Secondly, more articles dealing with real-world Education 4.0 initiatives were published in 2020. Again, this is so despite the fact that the search strings used were not year-specific.

Thirdly, according to the reviewed articles, most real-world Education 4.0 activities took place at both universities of applied sciences and traditional universities, and involved university undergraduate students. This includes those instances in which the exact number of participants was not provided. Fourthly, most of the reported Education 4.0 initiatives involved both specific academic subjects and generic academic disciplines. Regarding the latter, engineering is a generic academic discipline involved in most Education 4.0 projects, followed by computer science. Fifthly, four sets of Education 4.0 technologies and two sets of Education 4.0 technologies were identified as fully and near-fully integrated, respectively. Sixthly, ten sets of Education 4.0 technologies were classified as disruptive, scalable, and sustainable, and as holding the prospect to promote sustainable open higher education in accord with the UN's SDGs. Eighthly and lastly, the reviewed articles provided both specific and generic Education 4.0 technology affordances. However, with reference to most of the soft-skill affordances cited (especially the twenty-first century skills cited), the paper has argued that they are stylized facts as they predate Education 4.0 and are, thus, are not exclusive to it.

With regard to limitations, the current study was confined to the online databases it searched. In this case, it only reviewed sixteen articles. It did not review other forms of publications such as books and book chapters, and in doing so, it could have overlooked other real-world Education 4.0 initiatives documented in such publications. Nevertheless, it omitted these publications for uniformity and consistency purposes. Additionally, the reviewed articles were limited to those published in English.

Finally, more research on the real-world applications of Education 4.0 in the HE sector is needed. This is particularly so as there appears to be more conceptual and theoretical academic papers that focus on Education 4.0 than those that report on practical, real-world applications of Education 4.0 at HEIs. Despite the limitations associated with the current paper, the paper lends itself well as one of the key reference points for future studies on the real-world applications of Education 4.0 in the HE sector.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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