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Education and the Fourth Industrial Revolution: Eight Years Later

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Abstract

This paper delves into the transformative impact of the Fourth Industrial Revolution (4IR) on various sectors, with a particular focus on education. Divided into three comprehensive sections, the first part explores the dynamics of 4IR, detailing the technological advancements and innovations that characterise this era, such as artificial intelligence, robotics, the Internet of Things (IoT), and big data analytics. The second section examines the application of these 4IR technologies in the educational landscape, highlighting how they are reshaping teaching methodologies, learning environments, and administrative processes. This includes an analysis of smart classrooms, personalised learning experiences, and the integration of digital tools in curriculum delivery. The third section envisions future possibilities, considering the potential long-term impacts of 4IR technologies on education and society at large. It discusses emerging trends, potential challenges, and opportunities for further innovation. The paper also addresses some arguments against the existence of an Industrial Revolution, questioning whether the changes we are witnessing constitute a true revolution or merely an evolution of existing technologies. The conclusion summaries the key discussions, emphasising the need for adaptive strategies to harness the full potential of 4IR in education while critically evaluating the concept of an industrial revolution itself. Through this exploration, the paper aims to provide a comprehensive understanding of how 4IR is revolutionising education and what the future may hold.

Keywords: fourth Industrial Revolution, education, transformation and technology

Introduction

The Fourth Industrial Revolution (4IR), a term coined by Schwab (2016), signifies a change in thinking in global operations in general and the workings of societies in particular. The 4IR Schwab argued was going to drive rapid convergence in digital, physical, and biological technologies. This revolution was going to cause cataclysmic changes across different sectors in the society like business, agriculture, technology, and education amongst others. It was anticipated that like the third Industrial Revolution, the 4IR would lead to a complete transformation of the world of work in particular and life in general. Fomunyam (2019) adds that the integration of advanced technologies such as machine learning, artificial intelligence (AI), big data analytics, and immersive tools like virtual reality (VR) and augmented reality (AR) were expected to fundamentally shape and reshaped life and the society we live in.

Since Schwab's (2016) proclamation of the advent of the 4IR many scholars (Fomunyam, 2022b, 2023; Zawacki-Richter et al., 2019) theorised that the 4IR would dramatically change the educational sector or had the potential to change the sector through technological advancements aimed at enhancing pedagogical practices and learner engagement. Learning was going to be personalised with the evolution of AI, allowing for the tailoring of educational experiences that does not only cater for individual learning needs, but also individual pacing (Zawacki-Richter et al., 2019). Educators at all levels were expected to leverage all these technological tools to make education more exciting and engaging to students thereby improving their performance in particular and the responsiveness of the educational system in general. Chen et al., (2021) continues that the use of VR and AR technologies would bring about immersive learning experiences that transcend traditional classroom boundaries, offering interactive and experiential learning opportunities. These technologies facilitate deeper understanding of complex concepts by providing students with simulated environments and hands-on experiences.

Despite these advancements in VR, machine learning, artificial intelligence (AI), big data analytics, AR, AI, and AI powered chat bots', the integration of these 4IR technologies in education on a large scale is yet to be seen in the manner in which it was predicted. Furthermore, issues around digital equity, where disparities in access to technology can exacerbate existing educational inequalities, data privacy and security, all constitute concerns challenges that can be navigated (Selwyn, 2020). Additionally, the rapid pace of technological change necessitates continuous professional development for educators to effectively leverage these tools in their teaching practices. This paper seeks to explore the trajectory of educational practices over the past eight years amidst the ongoing advancements of 4IR technologies. By examining current trends, postulated advances, and the challenges faced by educational institutions in this era. The paper will provide an understanding of how the 4IR has affected education and its implications for future developments. This paper will be divided into three parts; first it will explore the dynamics of the 4IR. Secondly, it will explore the application of 4IR technological advancements in education. Thirdly it will explore future possibilities. The paper will end with a conclusion which summarises the discussions.

The dynamics of the 4IR

The 4IR is marked by various groundbreaking technologies or the use of various groundbreaking technologies as some have claimed (Selwyn, 2020) to change the way industries or societal sector's function, as well as the way mankind sees its role in the world. One of the most pivotal innovations of the 4IR is artificial intelligence (AI), which encompasses machine learning, natural language processing, and robotics. AI systems can analyse vast datasets to make informed decisions, optimise processes, and enhance productivity across various sectors. As Schwab (2016) highlights, "AI is transforming industries by enhancing productivity and enabling new levels of personalisation" (p. 56). Adding to this Fomunyam (2022a) argues that in healthcare, for instance, AI algorithms can analyse medical images to show diseases at earlier stages, significantly improving patient outcomes. Moreover, the Internet of Things (IoT) plays a crucial role in connecting devices and systems to facilitate real-time data exchange. This interconnectedness leads to smarter infrastructure, as seen in smart cities where traffic systems and energy management are optimised through data analytics. Zawacki-Richter et al. (2019) assert that "the IoT enables real-time data collection and analysis, driving efficiency and innovation across sectors" (p. 94). As such the 4IR is not only challenging the way society works but is also engaging with it in the change process.

Furthermore, the continuous evolution of blockchain technology provides a decentralised and secure framework for recording transactions, enhancing transparency and trust in sectors like finance and supply chain management. Tapscott and Tapscott (2016) emphasize that "blockchain can serve as a trusted ledger for transactions, reducing fraud and increasing efficiency" (p. 58). This is further confirmed by Fomunyam (2022a) who posits that there is exciting potential in the utilisation of blockchain technologies in various applications, from digital identity verification to smart contracts. In addition, robotics and automation are further cornerstones of the 4IR, with robots increasingly integrated into manufacturing, logistics, and healthcare. Automation enhances operational efficiency and accuracy, with robots performing repetitive tasks that were traditionally labor-intensive. Collaborative robots, or cobots, work alongside human workers to improve productivity while maintaining safety standards (Brynjolfsson & McAfee, 2014). These advancements in robotics are also starting to find expression in education, as initiatives or lesson plans aimed at preparing students for a future that increasingly integrates automation are emerging (Fomunyam, 2022a).

To add to this, advancements in biotechnology and genetic engineering, particularly through clustered regularly interspaced short palindromic repeats (CRISPR) technology, have transformed the field of medicine and agriculture. CRISPR allows for precise editing of genetic material, paving the way for potential cures for genetic disorders and enhancements in crop resilience. Schwab (2016) notes that "biotechnological advances are changing our understanding of life itself" (p. 45). This brings to light both the promise, and the ethical dilemmas that would follow such advancements following gene editing. 3D printing, or additive manufacturing on the other hand represents another significant innovation within the 4IR, enabling the

creation of complex three-dimensional objects from digital designs. It fosters prototyping, customising, and material efficiency, thereby making the production of things that were previously thought impossible, possible. As these technologies evolve, they collectively illustrate the potential of the Fourth Industrial Revolution to not only enhance economic growth and productivity but also to transform everyday life.

Schwab (2016) characterises this revolution as "a range of new technologies that are fusing the physical, digital, and biological worlds" (p. 2). This fusion includes advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and biotechnology amongst others. The critically of these innovations particularly AI is vital in the enhancement of processes and can streamline processes and enhance customer experiences. This suggests that organisations should adopt or need to adopt these technologies to remain competitive. This is not without cost though since it is estimated that between 70 million to 375 million workers may need to transition to new occupations due to automation.

Finally, the Fourth Industrial Revolution presents unique opportunities to tackle pressing global challenges, particularly sustainability. Technologies such as IoT can optimise energy consumption, while AI can enhance resource management, providing vital tools in the fight against climate change. Schwab (2016) underscores this by stating, "the future should be shaped in a way that advances the economic and social conditions of all" (p. 5). Thus, as we navigate this complex landscape, it is imperative to harness these technologies responsibly, ensuring they enhance human well-being and foster a sustainable future for all.

4IR Technological Advancements and Education

AI has become a pivotal force in transforming education and educational methodologies. AI-powered tools, such as adaptive learning platforms, use sophisticated algorithms to tailor educational experiences to individual needs (Baker & Inventado, 2014). Baker and Inventado, (2014) continue that platforms like DreamBox and Carnegie Learning employ real-time data to adjust lesson difficulty and provide personalised feedback based on student interactions. DreamBox's algorithms dynamically modify content to match students' skill levels, fostering deeper engagement and understanding. Similarly, Squirrel AI offers personalised tutoring, addressing specific learning gaps and enhancing comprehension in complex subjects (Baker & Inventado, 2014). These innovations suggest a significant shift in educational practice driven by technological advancements. While these advances are amazing and worth noting, they are capital intensive and is not readily available to everyone educational institution. It is yet to be seen how local universities are taking advantage of these innovations. Furthermore, intelligent tutoring systems illustrate AI's impact on education. Systems such as Knewton and Carnegie Learning's MATHia simulate personalised tutoring by continuously adapting to students' needs (Whalley, France, Park, Mauchline, & Welsh, 2021). MATHia and Knewton are adaptive technologies that adjusts instructional content based on real-time student data, helping address difficulties in subjects like math. MATHia in particular is helping transform the

teaching and learning of mathematics in several quarters based on diverse levels of customisation. Almoubayyed et al, (2023) argue that this level of customisation supports a more individualised learning experiences allowing students to progress at their own pace and achieve a deeper understanding of the material. Technologies like this though quite innovative are yet to be adopted outside America and Europe where most of the sponsors of such innovations like the Carnegie Foundation are based. So, while the 4IR is producing innovations that can transform education globally, a lot of capital and political will is needed for these innovations to make a credible impact on education globally because most of these technologies are still in their initial stages and are yet to be fully adopted in the countries in which they are developed.

To add to this, virtual reality (VR) and augmented reality (AR) technologies have also demonstrated a potential to transform educational realities and experiences. Virtual reality and augmented reality have created immersive learning environments that extend beyond traditional classroom settings. VR applications like Google Expeditions enable students to explore historical sites, outer space, or the human body interactively (Chen, Huang, & Cheng, 2021). These immersive experiences facilitate experiential learning, enabling students to engage with content on a deeper level and gain practical insights into complex subjects (Chen et al., 2021). For example, VR simulations can immerse students in historical events, providing a firsthand experience that enhances their understanding of historical contexts (Chen et al., 2021). VR devices created by companies like Apple, Google amongst other are extremely expensive to be made available in the everyday classroom. AR technology complements VR by enhancing physical learning environments with digital overlays. Applications like Augment and AR Flashcards bring traditional educational materials to life through interactive 3D models and animations (Bailenson, 2018). AR Flashcards, for instance, transform static flashcards into dynamic learning tools by displaying interactive visualisations of objects or concepts. This integration of digital content with physical materials helps students visualise complex ideas, making abstract concepts more accessible and engaging (Bailenson, 2018).

Furthermore, the innovations of 4IR technologies have the potential to significantly transform pedagogical approaches as well as the curriculum design. Traditional teaching methods, often characterised by passive learning or rote memorisation, are increasingly complemented, or replaced by interactive and student-entered approaches. Data-driven insights from AI systems should enable educators to design lesson plans that respond to individual student needs, promoting a more personalised learning experience (Zawacki-Richter et al., 2019). For example, data analytics can find patterns in student performance, allowing educators to adjust pedagogical practices and provide targeted support. This personalised approach ensures that students receive tailored instruction that addresses their specific learning needs and preferences. VR and AR technologies are also transforming pedagogical strategies. Wang et al., (2022) argues that some of these innovations are being inculcated in MOOCS or on platforms that host MOOCS to make for better learning experiences. It has not only improved the offering of MOOCS, but online programs offered by some universities. Zhu et al., (2022) add that in medical education amongst others in universities like Stanford

employ VR tools such as Osso VR for surgical training. These VR simulations provide hands-on practice without the risks associated with real-life procedures, enhancing skill acquisition. The opportunity of perfecting one's skills before ever getting to work on an animal or a human being brings to light the advances of the fourth Industrial Revolution. Zhang and Xie (2021) argue that the United States in the K-12 sector, some schools are leveraging big data analytics to track student progress and create customised lesson plans. This way they improve student engagement and success by opening new pathways to learning, unlearning, and relearning.

Another of the possibilities of the 4IR is the contextual use of blockchain technology, which can be used as solution for academic accreditation, and verification of credentials. This is because embedded within it, is the potential for tamper-proof records of academic achievements, just like it has been used in other sectors. This is particularly vital in today's world where the validity of most academic credentials are being questioned and degree mills are popping up on a daily basis. For example, Akanbi (2024) reports that Nigeria on the 24 of August declared some 22700 degrees obtained from Togo and Benin Republic invalid. This was partly due to the inability of the government to verify these qualifications. With the engagement of blockchain technology in education such crisis would be averted. Technology could also streamline administrative processes, enhance transparency, and reduce the risk of credentialing errors. As blockchain technology continues to evolve, it may offer new methods for managing and verifying academic records, providing a more secure and efficient framework for educational credentialing. Furthermore, the Education Blockchain Initiative, a collaborative effort by the U.S. Department of Education and the American Council on Education, investigates how blockchain can ensure academic records are both accessible and tamper-proof, potentially replacing traditional, often cumbersome record-keeping systems (Office of Educational Technology, 2023; Liu, 2023). Blockchain's decentralised nature also provides resilience against data loss, allowing for consistent record integrity and long-term accessibility, even as students transition between institutions (Timoshenko & Alrubaie, 2023). Another significant application of blockchain in education is in credential verification, which has become essential for institutions, employers, and students. Blockchain-based platforms like Blockcerts, co-developed by MIT Media Lab and Learning Machine, enable institutions to issue digital certificates that are immutable, ensuring their authenticity without the need for manual verification (Braun & Lee, 2022). Similarly, APPII uses a combination of blockchain and machine learning to confirm academic and professional credentials, thereby streamlining the process for individuals to present verified qualifications to employers or other educational institutions. These blockchain applications not only simplify the verification process but also reduce fraud and ensure greater trust across education and employment sectors. Blockchain technology also introduces new opportunities for personalised, gamified learning experiences. Platforms like BitDegree offer tokenised rewards for course completion, incentivising student engagement and enhancing motivation through rewards such as digital scholarships or micro-credentials (Mueller, 2023). Additionally, Disciplina uses blockchain to store individualised educational profiles, which allow educators to tailor learning pathways based on students' prior achievements and needs, potentially leading to improved academic outcomes

(Blockchain in Education, 2023). These applications illustrate how blockchain not only secures educational records but also enhances the personalisation and accessibility of learning, paving the way for more adaptable and transparent educational ecosystems. The rise of robotics within this era of the 4IR have been an interesting phenomenon because robots or humanoids as some of them have grown to be called are able to perform all task. From being sexual partners to being teachers and emotional support structures. The emergence of distinct types of robots have also necessitated their use in education at all levels. In preschool it is used to teach and train pupils for basic tasks. It can also act as the teacher and guide the children in the absence of a teacher (Neumann, Koch, Zagami, Reilly, & Neumann, 2023). El-Khatib, El-Baradie, and Alrashedi (2024) and Gardenghi and Gherardi (2024) on the other hand, postulate that artificially intelligent robots as teachers (AI teachers) have attracted extensive attention due to their potential to relieve the challenge of global teacher shortage and realise universal elementary education by 2030. Despite mass production of service robots and discussions about their educational applications, the study of full-fledged AI teachers and children's attitudes towards them is quite preliminary. As such despite their adoption, there is still scepticism about their ability to socialise and train children to develop soft skills as well as build social and cultural capital based on experience.

Another aspect of the 4IR transforming education is the expatiation of digital literacy. Developing digital literacy skills among students is increasingly important as educational technologies evolve. Digital literacy includes not only technical skills but also the ability to critically evaluate and use digital information effectively (Redecker & Punie, 2017). Educational initiatives should focus on fostering these competencies to prepare students for the demands of a technology-driven world. For instance, curricula should include activities that develop students' abilities to navigate digital environments, assess the credibility of online information, and use technology responsibly (Redecker & Punie, 2017). By integrating digital literacy into education, educators can help students build the skills necessary to succeed in a rapidly changing technological landscape. However, the rise of digital literacy has raised questions about digital equity. Van Deursen and Van Dijk (2019) emphasize that efforts to bridge the digital divide must include investments in digital infrastructure and support for disadvantaged students. This includes initiatives to improve access to technology, provide affordable internet services, and support digital skill development in underserved communities. Policies that promote digital equity are essential for ensuring that all students have the opportunity to benefit from technological advancements. This, many countries are yet to do and the lack of policy in addressing these disparities have ensured that those in disadvantageous spaces remain more disadvantageous.

Fourth Industrial Revolution and Future Possibilities in Education

Despite the benefits of 4IR technologies, several challenges must be addressed to ensure their effective and equitable implementation. One major concern is digital equity, and this is critical because disparities in access to technology and reliable internet connectivity can exacerbate educational inequalities, particularly for students from

economically disadvantaged backgrounds (Selwyn, 2020). A lot more needs to be done to ensure connectivity and the availability of these multiplicities of innovations to all students globally. Students lacking access to modern devices or stable internet connections may struggle to fully participate in technology-enhanced learning opportunities, leading to disparities in educational outcomes (Selwyn, 2020). Addressing digital equity requires comprehensive strategies, such as investing in digital infrastructure, providing affordable technology, and implementing policies that ensure all students have access to necessary resources (Selwyn, 2020). This have to be done in line with data privacy and security concerns in mind. This is because the use of AI and learning analytics involves collecting and analysing extensive student data, raising concerns about the protection of personal information (Greller & Drachsler, 2016). Educational platforms that collect data on student performance and behaviour must implement robust security measures to safeguard this information from unauthorised access. Custers (2016) emphasises the importance of transparency and security in managing educational data to protect students' personal information from misuse. Implementing strong data protection protocols and ensuring transparent data handling practices are essential for maintaining trust and protecting student privacy.

Adaptive learning is another area which can be revolutionised by the 4IR. Real-time adaptive learning experiences could become far more advanced, with AI not only assessing a student's progress but also using predictive analytics to anticipate challenges before they arise. This could enable teachers to address potential learning gaps proactively, providing interventions at critical moments rather than after problems surface. For example, AI systems might develop capabilities to assess students' stress or confusion levels based on subtle cues—like voice modulation or typing speed—suggesting support materials accordingly to enhance learning efficiency (Srinivasan, 2022). This would ensure meaningful learning for all students and ensure that their learning experiences are at par.

Another emerging possibility is the development of "digital twins" of educational environments, which could fundamentally change how we understand and assess learning. Digital twins, initially popular in industries like manufacturing, replicate real-world systems virtually and allow continuous experimentation and optimisation (Frontiers, 2023). In an educational context, digital twins of classrooms could allow for the simulation of diverse instructional strategies and learning models to see which approaches best benefit different student demographics before they are applied in actual settings. This innovation would empower educators to create optimised learning environments, tailored to the unique needs of various student groups (World Economic Forum, 2023). This would not only create pedagogical practices that enhance learning but are responsive at all levels.

Again, biotechnology could also expand in education, particularly through cognitive enhancement tools. Neurotechnology, for instance, could one day support customised learning pathways base on a student's brain activity and cognitive strengths. Emerging brain-computer interfaces could potentially facilitate new ways for students to learn, offering direct interaction with digital content through thought alone, and offering unique ways to support students with disabilities. Although such technologies raise

ethical considerations, they hold the potential to improve educational inclusivity and learning efficiency in ways previously unimaginable (Frontiers, 2023).

Furthermore, decentralised blockchain-based credentialing systems may advance further, not only securing educational records but potentially facilitating lifelong learning portfolios. Rather than traditional degrees, students could curate ongoing, blockchain-verified records of skills and competencies acquired through various learning experiences—both formal and informal—over their lifetimes. This could enable learners to demonstrate a more nuanced skill set tailored to the specific needs of employers and align educational pathways more closely with professional development goals. This can also help curate alternative pathways for learning and professional development thorough the analysis of their credentials. This can also be done through the integration of quantum computing into education. This is particularly vital since quantum computing have the potential to solve complex problems at speeds far beyond what current technologies allow. Quantum-driven algorithms could perform intricate simulations for all aspects of education for current and future purposes, allowing students to experiment with advanced concepts in real-time. This leap in computing power could drive breakthroughs in personalised education, enabling students to engage in hands-on experiences with advanced sciences earlier in their educational journeys.

Another promising innovation lies in developing "neuroadaptive" learning environments that leverage brain-computer interfaces (BCIs) to enhance personalised education. BCIs could detect student focus levels, emotional states, and engagement in real-time, allowing the system to adaptively modify content delivery. For example, if the technology senses a decline in engagement, it could shift to interactive methods or adjust the difficulty level to re-engage the student. This approach could significantly benefit learners with attention or sensory challenges and foster more immersive, responsive learning experiences (Srinivasan, 2022).

Another future possibility is "holographic teaching," where virtual holograms of expert instructors could teach in classrooms globally, even in resource-scarce areas. Holographic teachers could bring top-tier educators into any classroom, irrespective of geography, to demonstrate complex concepts interactively. This technology has already shown promise in medical and engineering fields for remote surgeries and model-based instruction, but its potential for mainstream education remains untapped (Mohammad, & Almarabeh, 2023). When this is combined with AI-powered "empathy engines", learning would be improved across the world. 'Empathy engines' could facilitate social-emotional learning (SEL) by interpreting students' emotional states and guiding them through exercises designed to develop empathy, resilience, and collaboration skills. Such tools could become essential as schools increasingly recognise the importance of emotional intelligence in overall student development. By leveraging natural language processing (NLP) and sentiment analysis, these AI tools could help educators address students' social and emotional needs, creating a more holistic approach to learning (World Economic Forum, 2023).

Finally, further into the future, bio-digital convergence could allow students to "upload" certain types of knowledge directly to the brain, bypassing traditional learning altogether. While this concept, popularised in science fiction, remains far off, research into neuroplasticity and memory encoding suggests it may one day be possible. Bio-digital integration might allow students to learn languages or acquire technical skills much more rapidly, potentially shortening formal education durations and focusing more on practical applications (Srinivasan, 2022). The possibilities of the fourth Industrial Revolution are endless and it affect education in ways that educational specialists are yet to theorise.

Concluding Thoughts

While the advancements associated with 4IR technologies have undeniably transformed education, it is worth questioning whether these changes constitute a new industrial revolution or merely an evolution of existing technologies and practices. Critics argue that the concept of a "Fourth Industrial Revolution" may overstate the novelty of these advancements and their impact on society. For example, Moll (2021) critiques the concept of the Fourth Industrial Revolution (4IR) by arguing that it lacks the transformative societal and economic shifts that define true industrial revolutions. Moll asserts that for an era to qualify as an "industrial revolution," it must not only introduce significant technological advancements but also fundamentally alter labor relations, social structures, and economic systems on a global scale. According to him, while recent digital innovations are impactful, they represent an evolution of the Third Industrial Revolution's connectivity and digital networks rather than a new paradigm entirely (Moll, 2021). Moll also highlights that the 4IR narrative, popularised by Klaus Schwab and the World Economic Forum, serves more as a rhetorical tool than a descriptor of real socioeconomic shifts. This narrative, he suggests, functions to sustain the neoliberal agenda by reinforcing an idealised future centred on rapid technological adaptation, while overshadowing persistent inequalities and limiting critical discourse on who truly benefits from these advancements. Moll argues that this ideology primarily benefits elite interests, with little evidence of widespread transformative impact on the broader global labor force (Moll, 2022). Edgerton (2020) adds that many of the so-called 4IR technologies are more limited in their impact than suggested, benefiting primarily advanced economies and specific sectors rather than catalysing widespread societal change. Freeman and Perez (2021) support this perspective, noting that, while these technologies enhance productivity, they often exacerbate existing inequalities by disproportionately affecting low-skill workers, who are more vulnerable to job displacement. Instead of fostering inclusive economic growth, these advancements may deepen the socioeconomic divide, raising concerns about the true societal benefits of the 4IR (Freeman & Perez, 2021).

However, it can be concluded that the Fourth Industrial Revolution has profoundly impacted education over the past eight years, with advancements such as AI, VR, and AR transforming teaching and learning practices. While these technologies offer numerous opportunities to enhance educational experiences, they also present

challenges that must be addressed to ensure equitable and effective implementation. However, it is important to critically assess whether these changes truly represent a new industrial revolution or simply an evolution of existing technologies. By focusing on issues such as digital equity, data privacy, educator development, and ethical considerations, stakeholders can work towards creating a more inclusive and dynamic educational environment that leverages the full potential of 4IR technologies. As we move forward, continued innovation and adaptation will be essential for shaping the future of education in a rapidly evolving technological landscape. Eight years after the declaration of the 4IR by Klaus Schwab, it is yet to transform the society and global economies like was predicted. However, there are a lot of possibilities for the future.

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