The Experiences of Engineering Students About the Fourth Industrial Revolution and Development: A Case in Gauteng Province

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Abstract: The Fourth Industrial Revolution has become the subject of much debate by scholars, different stakeholders, and politicians. The 4IR is an era where people are using smart, connected, and converged cyber, physical, and biological systems and smart business models to define and reshape the social, economic, and political spheres. South African educational institutions have difficulties, such as low levels of reading and writing proficiency, weak levels of logic and reasoning, and insufficient utilisation of technological resources. Due to the lack of an adequate supply of advanced engineering talent, South Africans would have to wait a long time before they can reap the benefits of innovation-led development. Beyond that, the skills need to be developed by people in regular jobs to deal with the disruptive effects of new technologies in their work environments. The 4IR requires certain skills that are not the same as the skills that were required in the 3IR. Thus, the 4IR continues to be desired by the majority of South Africans, especially engineering students, but this revolution is still challenging. In order to find a solution to the professional skills gap caused by the apparent disequilibrium and insufficiency of the South African educational system's skills, the aim of this paper is to investigate the experiences of engineering students about the Fourth Industrial Revolution and development. In order to determine if engineering education would continue to be offered at South African institutions of higher education in the 4IR age, this paper employs qualitative methods to identify an interpretive paradigm.

Keywords: Development, Engineering, Experiences, 4IR, Students, Universities

1. Introduction

The Fourth Industrial Revolution (4IR) is described as 'the fusion of technologies that is blurring the lines between the physical, digital, and biological spheres' (Schwab, 2019). The 4IR, as summarised by Schulze (2019), describes how technological advancements like artificial intelligence, autonomous vehicles, and the internet of things are influencing how people live their physical lives. The term "4IR" is credited to Klaus Schwab, the founder and executive chairman of the World Economic Forum (WEF) (Schwab, 2019). The 4IR is anticipated to have a significant impact on all facets of our everyday lives, including how people interact with technology and how we work, live, and do our jobs (Moloi & Marwala, 2020). From one country to the next, the 4IR's effects are different, and culture plays a pivotal role in this regard. Around 1760, the steam engine, a significant breakthrough, led to the First Industrial Revolution in Britain (Moloi & Marwala, 2020). At the conclusion of the 19th century, the Second Industrial Revolution began. Massive inventions in the fields of semiconductors, personal computers, and the internet were made during the Third Industrial Revolution (3IR) (Marwala, 2020). The 4IR is different from the 3IR because the digital, physical, and biological worlds are shrinking to an extent that it is practically difficult to differentiate between these worlds, and the rate at which technology is changing is faster than ever (Schulze, 2019).

The 4IR century has transformed teaching and learning in the universities that is rebranded by rapid technological advancements. Virtual reality and augmented reality and the internet of Things are 4IR technologies the study is focussing on. The use of ICT need to be used when teaching engineering students. There are massive use of zero-rated applications and educational websites, social media, Facebook, Twitter, WhatsApp, internet Websites, YouTube, Microsoft Teams, Skype, and Zoom that are used. The tools above are new technologies that are being discovered in the 4IR, but other tools were discovered in the 3IR, but now they are beginning to find new purposes due to the rapid convergence of advance technologies across the biological, physical, and digital worlds. Information,

knowledge, and innovation drive the engineering field, necessitating the development of both technical and soft skills (Forbes, Bielefeldt & Sullivan, 2015). Kayembe and Nel (2019) emphasise the reinvention of education systems and strategic approaches to increase creativity and innovation. Additionally, Mckinsey (2015) indicates that for South Africa to become a hub for global competition, the sector had to improve its capacity for innovation. In contrast, Rodny-Gumede (2019) contends that South Africa's educational system has not promoted innovative and creative thinking. Once more, in order to provide new interdisciplinary science programmes, institutions must be restructured in response to 4IR in education (Penprase, 2018). According to the 4IR, educational institutions must promote collaboration with other stakeholders including the government and private companies. Moreover, the investment by governments and higher education institutions in research and new university curricula is important to obtain the best results from new technological advancements.

Additionally, the 4IR demands brand-new skill sets. In a similar spirit, Fick (2019) notes that people in South Africa suffer from skills deficits that are much more fundamental than the ones people are being urged to address ahead of the 4IR. Some of the skills needed for 4IR are foundational skills such as Workforce Readiness, Soft Skills, Technical Skills, and Entrepreneurial skills (Gray, 2016). Despite the fact that engineering education begins in higher education, the seeds for creating a skilled engineering professional must be planted in fundamental engineering classes with both technical and soft skills (Fomunyam, 2019). Butler-Adam (2018) argues that appropriate skills for implementing, managing, and collaborating with new technologies are necessary for the 4IR to be implemented successfully in education. The technical skills that 4IR requires are the hardest to find in South Africa, according to Greyling (2019). According to Gray (2016), 35% of the skills that are crucial in today's workforce can change. Similarly, PwC (2017) claims that 4IR technologies and their applications frequently call for specialised skills above and beyond basic digital literacy. Universities have the mandate to help in the development of these skills because being excluded from universities also means being excluded from learning these specialised skills. They conducted workshops, seminars et cetera. Ramukumba (2019) reveals that the South African school curriculum does not equip students with the right skills and computer science skills for the 4IR. In contrast, Wanab (2020) stated that during the COVID-19 pandemic various learning institutions stopped face to face classes towards online learning. Dube (2020) posits that students adjusted to online learning, using various learning management systems and low-tech applications. Fomunyam (2020) indicates that a paradigm shift in curriculum revision with soft skills inclusion will add value to the engineering profession and its workforce.

Again, Mourtos (2015) makes the case that for older engineering educators, the requirement to give engineering students better professional skills together with emerging core skill prerequisites may seem terrifying. If this pattern of inadequate skill predictions is not properly addressed and becomes a national priority agenda, it may get worse in the future. According to Schwab (2016), the 4IR has the potential to cause social disruptions, but it is within the people's capacity to address them and implement the changes and policies required to adapt and thrive in our rapidly changing world. This study aims to investigate the experiences of engineering students about the 4IR and development in Gauteng Province. With the use of this study, engineering students will be able to explore new skills, new possibilities, opportunities, new creations, and new inventions for the 4IR.

2. Literature Review

2.1 What is the 4IR?

The (4IR) is the period in which nations all over the world are embracing technologies that are changing the game, such as artificial intelligence (AI), robotics, cloud computing, and the Internet of Things (IoT) (Schwab, 2016). The 4IR is a combination of our physical and biological worlds with these powerful technological technologies. Think ubiquitous computers, interconnected digital devices, intelligent robots, autonomous vehicles, gene editing, the printing of organic matter, and even brain enhancements (Gleason, 2018). The previous three industrial revolutions can be used to understand the 4IR.

2.2 The Experiences of Engineering Students About the 4IR and Development

Engineering and Science, Technology, Engineering, and Mathematics (STEM) disciplines are involved in the continuous process of modernisation and revolution (Carnevale, Smith & Melton, 2011). Engineers

are expected to possess soft skills in addition to the technical skills acquired. This will help engineers understand project objectives and be able to carry them out with the resources at hand (Litchfield, Javernick-Will & Maul, 2016). To meet the demands of the 4IR, engineering programmes are challenged to create innovative techniques to teach classes so that graduate students are prepared to take on the challenges in this present era. The engineering field requires a wide range of practical soft skills in addition to highly developed technical skills (Shvetsova & Kuzmina, 2018). Despite such needs in the engineering labour force, the academic engineering curriculum is developed to focus on technical skills, neglecting important 4IR soft skills.

The 4IR will require schools to properly prepare learners with the right tools to come up with new and innovative solutions to today's and tomorrow's problems facing society. If the right skills are not taught to every learner, this revolution can lead to greater inequality. With the right skills, all learners will succeed either in the job market or as entrepreneurs. Entrepreneurship in the 4IR will open up new opportunities that don't yet exist; the education that learners receive must equip them with the necessary skills to succeed as entrepreneurs (Ramukumba, 2019). Creativity, problem-solving, critical analysis, independent thinking, and analytical skills are some of the skills needed to exploit opportunities presented by the 4IR (Ramukumba, 2019). Educators must acquire the skills and tools necessary to prepare learners for opportunities in the 4IR.

2.3 Universities and the 4IR

According to Kehdinga and Fomunyam (2019), education is evolving in the twenty-first century exactly like it did throughout the previous three revolutions. The social and industrial changes happening in the 4IR, according to Kehdinga and Fomunyam (2019), explain and present new tendencies in the development of contemporary engineering education. Engineering schools encourage interdisciplinary research and the development of entrepreneurial engineers. The most in-demand 4IR disciplines with the best employment prospects are science, technology, engineering, arts, and mathematics. Data science and geoinformatics, according to Carrim (2022), are in high demand as new technologies and digital platforms generate massive volumes of data and alter how knowledge is created, accessed, and used.

Kehdinga and Fomunyam (2019) emphasised educational collaboration and industrial cooperation once more as crucial qualities to make trust for engineers' future employability. Delivering education in conjunction with society, business, employers, and the government is necessary for success in the 4IR. According to Oke and Fernandes (2020), the education industry is not yet fully prepared for the 4IR, particularly in Africa. On the other hand, according to Kayembe and Nel (2019), funding for education is insufficient for educational institutions to operate to their full potential. To succeed at educational institutions, the 4IR need significant financial support. Education is greatly gaining from the increased use of new technologies, particularly from artificial intelligence, which is causing computers to become faster, more intelligent, and smarter. Other new technologies that are benefiting education include robotics, 3D printing, the internet of things, cloud computing, and advanced wireless technologies. Even digital technologies that were discovered in the 3IR are being given completely new roles as a result of the availability of fast and dependable internet like 5G. As a result, these technologies are being rediscovered to the point that they now come within the category of new technologies. For instance, students are taking virtual lessons on their laptops and cell phones because to the fast internet.

2.4 The Skills Required for the 4IR

The 4IR has different skills requirements than the 3IR, which was primarily driven by information technology (Suganya, 2017). These skills are critical thinking, people management, emotional intelligence, judgement, negotiation, cognitive flexibility, as well as knowledge production and management (Suganya, 2017). Soft skills are important to an employee's career growth within an organisation. In their 2013 article, Knobbs, Gerryts, and Roodt highlight the lack of soft skills training for engineering graduates entering the mining business. According to Knobbs *et al*. (2013), while graduates are skilled in technical areas, they lack the soft skills needed to handle interpersonal challenges in the job.

2.5 The Change Brought by the 4IR in Higher Education

Reaves (2019) argues that online learning is the way of the future of education. Massive changes in industries will be brought about by technologies like artificial intelligence, nanotechnology, robotics,

and additive manufacturing, which will put pressure on education. According to Waghid, Waghid and Waghid (2019), the 4IR is fundamentally altering how universities run, particularly in terms of teaching and learning. Waghid *et al*. (2019) went on to argue that the 4IR can transform the way humans interact emanating from the evolution of technology from various fields such as: 'artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing.' The cosmopolitan human condition, which is the amplified merger of technologies across the physical, digital, and biological worlds, is also argued to be a priority by Waghid *et al*. (2019) in their argument that universities in South Africa should prioritise it.

Reaves (2019) asserts that education needs to be restructured in order to teach 21st-century skills like "flexibility, adaptability, observation, empathy, creativity, innovation, and learning how to learn" in degrees and across disciplines. Reaves (2019) went on to state that even online learning needs restructuring so that 21st-century skills are taught and be able to be practised. The 4IR fosters circumstances that have a big impact on what we teach, what we study, and how we contribute to the economy, the workforce, and society as a whole at our universities. According to Kupe (2019) and Carrim (2022), the 4IR necessitates that universities be repositioned in order to maximise our contribution to the reconstruction of South Africa's future and the ensuing development and employment. Prisecaru (2016) adds that social media platforms are used by 30% of the world's population. Online search platforms like Google Scholar and YouTube have become new vehicles for teaching and learning.

3. Theoretical Frameworks

Due to the rapid changes in the political, cultural, social, economic, and technical environments, 21st-century society expects a lot of its citizens. It is now increasingly difficult to function without personal computers, social networks and platforms, and cell phones, which were formerly thought to be frivolous, have had a significant impact on society (Magout, 2020). Nearly every aspect of our everyday life is impacted by these technologies, including business operations and teaching and learning. The society must adjust its knowledge and abilities in all spheres of life to keep up with these shifting circumstances (Magout, 2020). Youth must receive their education at a variety of institutions in order to provide them with the knowledge and abilities needed for the 4IR.

Unprecedented demand is placed on educational institutions to keep up with the needs and expectations of a society that are always changing. According to Reaves (2019), students today need different skills than they did 20 years ago in order to be equipped for the 21st century. Employers are currently looking for young individuals with modern skills including teamwork, interpersonal, and problem-solving skills. The importance of lifelong learning and its role in creating a knowledge society are top priorities (Moon & Seol, 2017). When the government is preparing students to live, work, and flourish in the twenty-first century, it is imperative to come up with fresh teaching and learning strategies. According to the shift in social attitudes toward education and how it is delivered, educators believe that technology has the potential to solve a variety of issues (Magout, 2020). As resources increasingly grow scarcer and demand for access to higher education of higher quality skyrockets, it is critical to reconsider traditional teaching and learning approaches as new educational technology become available. It is necessary to look into the impact of the technology revolution on skill development as well as the sector's general readiness. Many theories attempt to explain the problem of innovations in the education sector from various angles. The two theories that were taken into consideration for this study were Connectivism and Engagement.

3.1 The Connectivism Theory of Learning

The use of technology makes people interact with one another. The impact of technology on how we learn, live, and communicate is explained by connectivism (Downes, 2007). The connectivism theory combines relevant components of numerous learning theories, social structures, and technology to produce a potent theoretical framework for the digital age. According to Siemens (2006), all learning theories were created before technology had an impact on education. The proliferation of technology has made it impossible for learning to control the learner, and many tasks that were formerly performed by humans, such information storage and retrieval, are now handled by technology (Kop & Hill, 2008). The difficulty facing educators today

is creating training that works for both humans and technology (Downes, 2007). According to Siemens (2006), learning should be organised around the flow of knowledge across networks rather than simply being the general acquisition of knowledge. Learning is a process of linking specialised nodes or information sources, learning may dwell in non-human appliances, and ability to know more is more important than what is now understood, among other connectivism-related notions, which are presented by Siemens (2006) and Downes (2014). This theory establishes a link between human and technological knowledge.

3.2 Engagement Theory

According to Clarà and Barberà (2013), student engagement should be at the centre of learning activities where students connect with one another most frequently. Dickey (2005) asserts that social interactions and collaborations are significant so that learners become involved in a community of practice. All students are engaged in activities that include active cognitive processes like creating, problem-solving, reasoning, decision making, and evaluation (Magout, 2020). Further, engagement creates intrinsic motivation in students to learn due to the nature of the environment created and its activities (Magout, 2020). Magout (2020) asserts that technology helps to facilitate all aspects of engagement which are difficult to attain without technology. Online conversations, conferences, emails, chat, and video conferencing are all used by engagement theory to facilitate easy interaction among all participants. The positive impact that technology can have on human interaction and evolution is emphasised by engagement theory (Reaves, 2019). This theory connects to contextual learning, constructivism, and experimental learning because they emphasise project-based learning and collaborative efforts that produce authentic, creative work (Magout, 2020).

4. Methodology

For this study, interpretivism was chosen as the guiding paradigm. The qualitative approach was chosen by the researcher because it enables dialogue with the participants in authentic contexts where they can share their opinions, ideas, or beliefs about their actual experiences with the 4IR in their institutions. The interviews gave the researcher the chance to gather sensitive data that was rich in descriptions of university engineering students. All engineering students from the universities in South Africa's Gauteng Province made up the population of this study. The researcher chose the Gauteng Province based on the accessibility of the research sample and its proximity to the area.

The researcher used a case study research approach in this study to examine the experiences of engineering students about the 4IR and development in the Gauteng Province. The study was only conducted at five particular universities in South Africa's Gauteng Province. In this study, engineering students who are enrolled in their last courses at the five institutions in the Gauteng Province were chosen using a purposive sample technique. Cohen, Morrison, and Manion (2011) contend that a qualitative research study's sampling population must be relatively small in order to yield the intended results. The study's thirty-one (31) participants were chosen. In Tshwane, semi-structured individual interviews with fifteen participants were held. There were two focus groups set up. Sixteen people participated in the focus group discussions, which were held in Johannesburg. This was done in order to provide the researcher with engineering students' experiences about the 4IR and development in the Gauteng Province. The results may not be generalised but the focus is on the in-depth information and data provided by the participants. Participants made informed independent decisions about whether or not to take part in the study.

5. Data Collection

This study employed focus groups and semi-structured individual interviews. Thirteen participants from the universities in Tshwane participated in semi-structured individual interviews, and sixteen students from the universities in Johannesburg participated in focus groups. It was determined that the semi-structured individual interview was appropriate for this study since it gave participants the chance to share their opinions on the 4IR and development in the Gauteng Province. To learn more about the experiences of engineering students about the 4IR and development in the Gauteng Province, focus groups were also used as a data collection method. With the participants' consent, the researcher used an audio recorder to capture the interviews. The researcher was able to compare the several interviews that were utilised in the study and discover and develop the themes that emerged from the paper.

6. Data Analysis

Thematic data analysis was employed in this study. Due to its adaptability, thematic analysis is a frequently used qualitative analytical technique. This paper used an inductive method to data analysis. Braun and Clarke (2013) advise transcription of audio data, which entails playing a tape in extremely brief bursts and typing out what the researchers hear, as a pre-requisite to analysing the recorded data. Following the interviews, all audio recordings were transcribed verbatim. The transcriptions were attentively and carefully read, then read again to become familiar with their content. To discover significant themes that arose from the research, the transcripts were reviewed numerous times, and notes were taken, categorised, and organised in accordance with the study's objectives. A system for major theme clarification was established using this initial reading as a foundation. Codes were applied for ethical reasons as well as to safeguard the participants' and their universities' identities. The researcher looked for both little and large bits of data that would address the study's research issue before coding it. In order to identify recurring themes, the data were coded and categorised. By double-checking the coded data and ensuring that the data were utilised, the researcher reviewed themes. The report was written by the researcher, who had to select transcribed cases to highlight various topics. A notion was more likely to be regarded as the study's theme if it appeared in the text more frequently.

7. Results and Discussion

7.1 Theme 1: Lack of Appropriate Skills for the 4IR

Individual interviews revealed that engineering students lacked the necessary abilities for the 4IR. Once more, the results of focus group discussions showed that students lack the necessary skills for the 4IR. Interviews revealed that the 4IR was introduced hastily when students lacked the necessary competencies. The majority of participants agreed that South Africa lacks the necessary technical, soft, entrepreneurial, and workforce skills. To support the aforementioned claim, participants noted:

> *FEJA (Focus Group A): "The 4IR requires the appropriate skills." FEJB (Focus Group B): "Skills challenges are real." ES1 (Engineering Student 1): "Students do not have appropriate skills for the 4IR." ES2: "We implore the government to give students the training they need for the 4IR." ES3: "Engineers must have soft skills in addition to their technical training." ES4: "Students should be ready to develop the necessary skills for the 4IR." ES5: "To improve collaboration and employability in the future workforce, educators and students should be encouraged to participate in skill development training." ES6: "South Africa has sadly struggled to generate a highly skilled workforce, which the 4IR demands." ES7: "Engineering students lack soft skills."*

The above narratives indicate that engineering students have inadequate skills for the 4IR. Reaves (2019) makes the argument that students today need different kinds of abilities than they did twenty years ago in order to be equipped for the 21st century. According to Magout (2020), society must adapt its knowledge and abilities in all spheres of life in order to stay up with the changing circumstances. The technical skills that 4IR requires are the hardest to find in South Africa, according to Greyling (2019). Similar to this, PwC (2017) claims that 4IR technologies and their implementations frequently call for specialised skills above and beyond basic digital literacy. In the same vein, Suganya (2017) contends that key skills necessary for the 4IR differ from those needed for the 3IR. It could be argued that universities struggle to prepare engineering students for the needs of the 4IR. Knobbs *et al.* (2013) also highlight the lack of soft skills training for engineering graduates joining the mining industry.

7.2 Theme 2: Redesigning the Curriculum to Satisfy 4IR Requirements

Individual interviews revealed that institutions should update their curricula to comply with the 4IR. Findings from individual interviews with engineering teachers revealed that they should possess in-depth knowledge of the engineering field as well as enough support for the growth of their professional abilities through access to top-notch learning opportunities. The results of focus group groups showed that teachers should be knowledgeable about the engineering field in order to prepare future engineering graduates to successfully complete their study and enter the workforce. Most participants agreed that curriculum should be changed to better match the requirements of society and the 4IR. The following remarks serve as proof for the answers given above:

ES1: "Our education cannot make us to find employment." FEJB: "Educational institutions' curricula should be reviewed for development, and they should also be in line with societal demands and take the 4IR into consideration." FEJA: "The 4IR should be considered in university curricula." ES2: "Curriculum should continuously change to match the needs of the period and environment". ES3: "Universities should redesign their courses to accommodate the demands of the 4IR." ES4: "Engineers with advanced degrees and a variety of skills explain problems and enhance the curriculum."

The aforementioned enlightenments indicate that curriculum revision should be pertinent to societal and 4IR needs. According to Kupe (2019) and Carrim (2022), the 4IR necessitates that universities be repositioned in order to maximise our contribution to the reconstruction of South Africa's future and the ensuing development and employment landscape. Oke and Fernandes (2020) contend that the African continent's educational system is still not completely ready for the 4IR. The engineering profession and its workforce will benefit from a paradigm change in curriculum modification that includes the incorporation of soft skills, according to Fomunyam (2020). On the other hand, Kehdinga and Fomunyan (2019) stress the significance of industrial and educational collaboration. It might be argued that the Connectivism idea links human and technological knowledge. According to Magout (2020), technology makes all aspects of involvement easier to achieve than they would be without it. The 4IR seems to be ignored by educational institutions' curricula, and what engineering students are taught must be related to the 4IR's requirements. The active cognitive processes of creation, problem-solving, reasoning, decision-making, and evaluation are being used by all students.

7.3 Theme 3: Increasing Creativity and Innovation

Individual interview data put a strong emphasis on creativity for the 4IR. Once more, the study showed that the 4IR requires the creation of novel products and business models. The results of focus group groups suggested that universities should foster a culture of creativity and innovation. The following statements captured the opinions of the participants:

FEJA: "More funding for research and development is required." ES3: "Research and development have a crucial role in driving innovation in the 4IR." FEJB: "Innovation is significant in South Africa."

Participants' quotes and comments in the aforementioned responses provide evidence that South Africa is innovative. Ramukumba (2019) argues that creativity, problem-solving, critical analysis, independent thinking, and analytical skills are some of the skills needed to exploit opportunities promoted by the 4IR. According to Mckinsey (2015), for South Africa to become a centre for global competition, the sector had to improve its capacity for innovation. The importance of reimagining educational systems and adopting tactical techniques is stressed by Kayembe and Nel (2019). According to Forbes, Bielefeldt, and Sullivan (2015), the engineering field is driven by information, knowledge, and innovation, all of which call for the development of technical and soft skills. In contrast, Rodny-Gumede (2019) contends that South Africa's educational system has not promoted innovative and creative thinking.

8. Limitations of the Study

A potential barrier to the generalisation of results was the study's confinement to just five universities in the Gauteng Province. It will be necessary to do additional research with numerous universities from every province in South Africa. The information provided by the participants may potentially be prejudiced, poorly reconstructed, or provide false descriptions of the circumstances at hand. Data was collected using focus groups and semi-structured individual interviews to prevent such occurrences from skewing the study's conclusions. Using the qualitative method as the research strategy could limit the investigation.

9. Conclusions, Recommendations and Implications

This paper set out to investigate the experiences of engineering students about the 4IR and development in Gauteng Province. In order to gather information from the engineering students enrolled in the universities in the Gauteng Province of South Africa, an interpretive qualitative study with a case study was used, as well as data collection methods such as semi-structured individual interviews and focus group discussions. The two theories that were taken into consideration for this study to investigate the problem around the experiences of engineering students about the 4IR and development in Gauteng Province were Connectivism and Engagement. By incorporating new skills abilities from the 4IR platforms, the skill gaps should be

filled, preparing engineering students for greater performance in the workplace. Refocusing on the quality and advancement of engineering education is necessary. Additionally, the expansion of insightful engineering programmes should be centred on planning and labour market assessment the extension of experiences engineering programs should be focused on planning and labour market analysis in the 4IR period. In order to spend more in engineering education, technical and soft skills instructional training should be made available, and the curriculum should be changed to reflect the 4IR age. The 4IR should demand the proper expertise.

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