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Developing Adaptability: Becoming a 4IR Ambidextrous Engineer in South Africa

Luigi Liccardo [a], Sabrina Liccardo [b*], and Jenika Gobind [c]

[a] *Wits Business School, University of the Witwatersrand, Johannesburg, South Africa*
[b] *Department of Psychology, University of Pretoria, Pretoria, South Africa*
[c] *Wits Business School, University of the Witwatersrand, Johannesburg, South Africa*
**Corresponding author. Email: sabrina.liccardo@up.ac.za*

Adaptability is key to coping with the disruptions brought about by the Fourth Industrial Revolution (4IR) and COVID-19. According to the World Economic Forum's Future of Jobs Survey, analytical thinking, resilience, flexibility and agility are the most sought-after core skills in 2025. Although researchers emphasise the central role of adaptability in coping with 4IR disruptions, little guidance is provided on how to become adaptable, particularly within engineering. Given this research gap, the article aims to: (1) examine if 3IR engineers are adaptable when faced with 4IR disruptions; (2) determine the kind of engineer that will be well-suited to cope and adapt to any disruptions faced during 4IR; and (3) investigate whether higher education institutions should modify engineering curricula to teach adaptability. The study adopted a qualitative design approach using online semi-structured interviews with 12 engineers currently working or teaching in the engineering industry. The interviews were analysed using thematic analysis. To explain the mechanisms involved in being a 4IR Ambidextrous Engineer, we propose the framework of the *Adaptability Machine*, which consists of the self-awareness central gear, intrapersonal gear, interpersonal gear and environmental gear. Drawing on the themes within this framework, we discuss the skills and environments conducive to coping with and adapting to any disruptions faced during 4IR. We conclude with a discussion of how higher education institutions could modify engineering curricula to assist engineering students in becoming 4IR ambidextrous engineers.

Keywords: *Adaptability; engineers; self-awareness; higher education; 4IR*

Introduction

The Fourth Industrial Revolution and Higher Education

The Third Industrial Revolution (3IR) provided the world with technological marvels such as semiconductors, computers and the Internet. We have had over 40 years to become accustomed to this technology, and we have adopted it to such an extent that technology has infiltrated every aspect of life. The term the Fourth Industrial Revolution (4IR) was coined by Schwab (2016), in which he envisaged 4IR reshaping disciplines, economies and societies to the extent that our understanding of what it means to be human and how we perceive reality will be challenged. The Fourth Industrial Revolution is characterised by new technologies that blur the lines between the physical, digital and biological domains, which makes this Revolution fundamentally different from all previous revolutions (Schwab, 2016).

Higher education institutions needed to adapt to the onset of each industrial revolution to supply the skills required by workers to stay relevant in the workforce. Furthermore, COVID-19 accelerated the onset of 4IR. In August 2021, the University of Johannesburg (UJ) announced a free introductory course on 4IR. In an interview with a South African media house, Professor Tshilidzi Marwala – former Vice-Chancellor and Principal of UJ – stated that the course was part of UJ's strategy to become Africa's leader in 4IR and prepare students, staff and community for 4IR. Marwala (2021: 12) maintained that '4IR is a catalyst which will transform society and its inclusion in the curricula is therefore required. Be adaptable, because 4IR is really about adaptability'. Following the work of John Wall, Joyner et al. (2012) argue that with each industrial revolution, engineering has rapidly evolved and become a social activity. For instance, Beder (1998, p. 57) writes: '[the] image of an engineer as technically inclined and socially introverted is increasingly outdated. Engineering is an intensely social activity, and engineers today are well aware of the social dimensions of their work.' Accordingly, Elegbe (2015), Lappalainen (2015) and Lopes et al. (2015) all maintain that engineering education must focus not only on technical expertise but also on socio-emotional skill development.

4IR Skills

Owing to the rapid pace at which technology is changing and improving, workers are forced to continuously upskill to stay relevant during 4IR, thus placing a premium on adaptability, self-directed learning and critical thinking (Penprase, 2018). The intrapersonal (within oneself) and interpersonal (between people) skills of self-awareness, self-regulation, motivation, empathy, social skills, resilience and flexibility are vital for professionals, including those in the fields of science, technology, engineering and mathematics (STEM), to adapt to disrupted workplaces and remain relevant in the future (Harari, 2018). Since 2015, the World Economic Forum (WEF) has surveyed chief human resource and strategy officers at leading global companies to track the predicted cross-functional skills required for future workforces. The World Economic Forum (2016, 2023, 2025) has published the results of these surveys in its Future of Jobs Reports. The required skills for 2020 and 2025 saw emotional intelligence ranked sixth and eleventh, respectively. In 2016, the WEF anticipated that the demand for social skills, such as persuasion, emotional intelligence and teaching skills, would continue to increase when compared with narrow technical skills such as programming or equipment operation and control. Furthermore, analytical thinking is the top sought-after skill in 2025, followed by resilience, flexibility and agility, leadership and social influence, 'underscoring the critical role of adaptability and collaboration alongside cognitive skills' (World Economic Forum, 2025, p. 35).

Problem Statement and Research Questions

Adaptability is key to coping with the disruptions that the onset of 4IR and COVID-19 has brought about. Although research emphasises the central role of adaptability in coping with 4IR disruptions (cf. World Economic Forum, 2016, 2023, 2025), little guidance is provided on how to become adaptable. We are particularly interested in 4IR preparedness in engineering. In this article, we investigate whether engineers are being prepared to navigate potential challenges brought about by 4IR and COVID-19. Although engineers are technically aware by virtue of their training, the development of intrapersonal and interpersonal skills, which improve dexterity to cope with 4IR and COVID-19 disruptions, may be lacking in their training as engineers. Given the research gap in how one prepares to become a 4IR ambidextrous engineer in South Africa, the main focus of this study aims to investigate engineers' levels of readiness in the face of disruption. In particular, we will address the following three research questions:

(1) Are 3IR engineers adaptable when faced with disruptions forecasted by 4IR and COVID-19?
(2) What type of engineer will be well–suited to cope and adapt to any disruptions faced during 4IR?
(3) Should higher education institutions adapt engineering curricula to include self-efficacy skills and awareness to assist students in becoming 4IR Ambidextrous Engineers?

In addressing these research questions, we have used two terms to differentiate between two 'types' of engineers. First, the term *3IR Engineer* was used for engineers who have completed their studies and spent most of their careers working in the 3IR, that is before 2015. Second, the term *4IR Ambidextrous Engineer* describes engineers who adapt to 4IR disruptions by being self-aware and balancing technical and socio-emotional skills.

Conceptual Framework and Literature Review

In this section, we draw on the theory behind the Myers–Briggs Type Indicator (MBTI) as a guide to discuss the characteristics associated with being a 3IR engineer and becoming a 4IR Ambidextrous Engineer. We then discuss how adaptability can be developed through emotional intelligence and self-awareness. The MBTI, developed by Myers and Briggs (Myers, 1962), is based on Carl Jung's theory of psychological types, which proposed common patterns of differences (cognitive functions) in how individuals prefer to use their minds (Jung & Baynes, 1924). The MBTI allocates preferences to each cognitive function, indicating the comfort level with which an individual carries out each function. The preferences proposed by Myers and Myers (1995) are defined by the way an individual prefers to: (1) focus their attention ranging from the preference of extroversion (E) to introversion (I); (2) perceive ranging from sensing (S) to intuition (N); (3) judge ranging from thinking (T) to feeling (F); and (4) deal with the outside world ranging from judging (J) to perceiving (P). The combinations of these preferences comprise the 16 MBTI personality types (Myers & Myers, 1995). The preference that an individual feels most comfortable utilising is called the 'Dominant Process', with the opposite side of the scale referred to as the 'Auxiliary Process' (Myers & Myers, 1995).

An MBTI Profile of Being a 3IR Engineer

Culp and Smith (2001) compared the MBTI profiles for 218 project engineers and managers. The study results showed that 25% of the engineers have an ISTJ indicator type. The study also reported that the six TJ preference types (ISTJ, INTJ, ESTJ, ENTJ) ranked in the top four of the 16 types and comprised a surprisingly high 52% of all the engineers assessed (Culp & Smith, 2001). In 2009, Culp and Smith updated their study with a much larger dataset comprising 740 professional consulting engineers from 13 different consulting firms. In this study, they found that consulting engineers have an indicator type preference of introversion (55%) over extraversion (45%), sensing (51%) over intuition (49%), thinking (74%) over feeling (26%) and judging (71%) over perceiving (29%). The preference was very prevalent in the thinking-feeling and judging-perceiving processes, where of the 740 engineers, 74% had a thinking preference and 71% had a judging preference. Culp and Smith's (2009) research implies that 71% of the engineers who participated in their study would not be considered adaptable.

Towards Becoming a 4IR Ambidextrous Engineer

A typical 3IR engineer—and all other individuals—use all eight process types in daily life, but to different degrees of comfort. To use the analogy of right-handedness vs. left-handedness, if one is right-handed, a person prefers to utilise one's right hand, but it does not mean that the person never uses the left hand. Myers and Myers (1995) introduced the notion of type-development as the advanced development of perception and judgment cognitive functions. Perception determines what a person sees, and judgment determines what one decides to do about it (Myers & Myers, 1995). According to Myers and Myers the ideal problem-solving methodology is to utilise the four perceiving and judging process types in the following sequence: (1) the utilisation of sensing to determine all the facts; (2) the use of intuition to consider all possible solutions; (3) the use of thinking to select the most feasible solution; and (4) finally incorporating feeling to consider the effect of the solution in human terms.

Individuals are not born with dominant processes for the perceiving and judging cognitive functions; instead, both process types (sensing/intuition and thinking/feeling) are used during the early stages of life. The dominant processes only take form later in life, during which an individual relies on their dominant functions with ease and confidence (Myers & Myers, 1995). Myers and Myers

(1995) claim that type-development only occurs in a few individuals where the auxiliary processes are further developed and balanced with the dominant process. Type-development allows individuals to understand and work through the deficits of their dominant process, which results in well-balanced individuals who have excellent levels of perception to make sound decisions. The concept of type-development is also relevant in developing adaptability. Even though research indicates that 3IR engineers seem more comfortable using the judging process type (Culp & Smith, 2009), 3IR engineers must practice becoming ambidextrous in utilising both their MBTI dominant and auxiliary processes. Achieving this dexterity will allow the 3IR engineer to be more flexible, adaptable and open to change. We use the term *4IR Ambidextrous Engineer* to describe self-aware and adaptable individuals who have become skilled in utilising both their auxiliary processes and dominant processes.

Developing AQ Through Emotional Intelligence and Self-awareness

Fratto (2018) paints a scenario in 2045 where ‘The AEI’ is a standardised test, replacing the SAT (Scholastic Aptitude Test), that assesses three variables: Adaptability Quotient (AQ), coined by Parkin (2010), Emotional Quotient (EQ) and Intellectual Quotient (IQ). Similarly, Smit (2021) proposes a ‘4IR success equation’ that to be successful in 4IR, one needs to combine intellectual, emotional and adaptability intelligences (4IR success = IQ + EQ + AQ). Adaptability is defined by the American Psychological Association as ‘the capacity to make appropriate responses to changed or changing situations; the ability to modify or adjust one’s behaviour in meeting different circumstances or different people’ (VandenBos, 2007: 17). The theory of EI, developed by Salovey and Mayer (1990), lies in the intersecting domain of emotion and cognition. Mayer, Roberts and Barsade (2008: 511) define EI as ‘the ability to carry out accurate reasoning about emotions and the ability to use emotions and emotional knowledge to enhance thought’.

Goleman and Boyatzis (2017) conceptualise EI as comprising four domains, namely: (a) self-awareness; (2) self-management; (3) social awareness; and (4) relationship management. Zhang, Cao and Wang (2018) adapted Goleman’s EI framework in four quadrants in which the columns represent the aspects of ‘self’ and ‘other’ (or intrapersonal and interpersonal aspects), whereas the rows represent the aspects of ‘recognition’ (self-awareness and social awareness) and ‘regulation’ (self-management and team management). Zhang et al. thus demonstrate that the aspect of recognition (or awareness) must be first attained before one’s focus can move over to regulation. By applying the EI notion of recognition before regulation to AQ, we argue that before one can start developing adaptability, one needs to be self-aware to evaluate the extent of one’s adaptability, strengths and weaknesses, and dominant and auxiliary processes. Owing to the commonality of self-awareness in both EQ and AQ, we have factorised Smit’s (2021) 4IR success equation as follows: 4IR success = IQ + self-awareness [EQ + AQ]. In other words, to be successful in 4IR, one needs to combine intellectual intelligence and self-awareness (which includes both emotional and adaptability intelligences).

Methods

This research study was conducted by the first author, a mechanical engineer, in partial fulfilment of the requirements of his Master of Business Administration degree. The co-authors served as academic supervisors for this research study. Purposive sampling was used to recruit participants who met specific inclusion criteria, combined with snowball sampling to extend recruitment through participant networks. Once ethical approval was obtained from Wits Business School, semi-structured interviews were conducted virtually owing to the worldwide lockdowns as a result of the COVID-19 pandemic, with 12 engineers who had graduated from a higher education institution and are currently working or teaching in the engineering industry for a minimum of 10 years (see Table 1).

The sample size was determined by data saturation, where no new themes or information emerged from data collection (Braun & Clarke, 2021).

Table 1. Participant profiles

Pseudonym	Sex	Age	Race	Country of birth	Years living in South Africa	Job title	Higher education qualification attained
Thato	M	43	Black African	RSA	–	Director	BSc and MSc Mechanical Engineering
Anna	F	38	Black African	RSA	–	Electrical engineer	BTech Electrical Engineering, BCom Financial Accounting, PGDM Management Practice
Barnard	M	48	White	RSA	–	Project manager	BSc and MSc Electrical & Electronic Engineering
Colin	M	46	Black African	RSA	–	Engineering manger	BSc Mechanical Engineering
Alex	M	59	White	PT	57	Executive officer	ND, PGDip and MSc Civil Engineering
Gugu	F	43	Black African	RSA	–	Senior lecturer	BSC (Hons) and MSc Microbiology, Biochemistry and Zoology, PhD Environmental Engineering
Peter	M	58	Black African	DRC	18	Lecturer	BSc, MSc and PhD Chemical Engineering
Sibusiso	M	42	Black African	RSA	–	Senior mechanical engineer	BSc and GDE Mechanical Engineering
Leo	M	53	White	RSA	–	Lecturer	BSc Electrical Eng., BSc (Hons) Theoretical Physics, BSc and MSc in Applied Maths, MBA
Alfred	M	35	Indian	RSA	–	Senior manager Strategy	BSc Chemical Engineering
Ed	M	36	Indian	RSA	–	Executive Officer EC&I	BSc Electrical and Electronic Engineering
Nicci	F	48	White	ITA	13	Associate professor	BSc, MSc and PhD Aeronautical Engineering

Note: RSA, Republic of South Africa; PT, Portugal; DRC, Democratic Republic of Portugal; ITA, Italy.

Data Analysis

The interviews were audio-recorded and transcribed, and a thematic analysis (Braun & Clarke, 2006) approach was adopted. First, the familiarisation of data involved transcription and rereading the transcripts. The transcripts were then coded using ATLAS.ti 22 software. An in-text reference such as this (6:14 ¶ 51 Gugu.docx) is indicative of the coding. The codes were then organised into themes, which were reviewed several times by the researchers. These themes and supporting extracts were then interpreted in relation to the research questions and literature review.

Credibility, transferability, dependability and confirmability are the criteria to ensure trustworthiness and quality in qualitative research (Korstjens & Moser, 2018). The strategy utilised in this study to ensure credibility was a member check, where the researcher's interpretations and conclusions were fed back to the participants. In so doing, the data are strengthened—made credible—as researchers and participants view the data through different lenses. Transferability was ensured in this study by providing 'thick descriptions' of the participants' narratives. To verify dependability and confirmability in this study, all research steps were transparently described, and records of the research path have been kept throughout the study. Inter-rater reliability aims to 'mitigate interpretative bias' and to ensure consistency is maintained across coding (Walther, Sochacka & Kellam, 2013: 650). Although the first author carried out all necessary coding, the second author acted as an inter-rater and performed an independent coding exercise on a portion of the transcripts to facilitate thematic reliability and trustworthiness in the data analysis and presentation of findings. The raw inter-rater agreement reached 81%, and the Holsti coefficient of reliability was 0.81, which is considered an acceptable level of agreement (Mao, 2017).

Findings and Discussion

In this section, we examine whether 3IR engineers are adaptable, the type of engineer that is well-suited to cope and adapt to any disruptions faced during 4IR, and how higher education institutions could modify engineering curricula to include self-efficacy skills and awareness that would assist engineering students to become more adaptable.

A Research-driven Definition of Adaptability

Gugu states that to be adaptable, one must be comfortable 'with not knowing, being comfortable in the absence of certainty'. Leo believes that he is more adaptable than 3IR engineers as he enjoys delving into problems and undertaking tasks that he has very little knowledge of:

> Leo: I always like to be doing something that I don't know anything about. And for a lot of people, that's absolutely insane, right? Yeah, so I like delving into problems where I'm completely ignorant, where I've got to learn, okay, so for me, it's personally all about learning.

Similarly, Colin argues that people feel vulnerable when not knowing and learning something new: 'Now, suddenly, when you're learning something new, people tend to feel vulnerable, and no one wants to feel vulnerable. People want to feel that they're in control.'

Leo also suggests that one needs to embrace the vulnerability that is associated with not knowing:

> Leo: Being comfortable in that, not even comfortable, but just willing to embrace the unknown. Okay, you know, when you're delving into the unknown, it's actually uncomfortable. And they have to be willing to accept being uncomfortable. You know, and not be disheartened by that.

Therefore, a definition of adaptability formulated from Gugu, Leo and Colin's excerpts is the ability to embrace the discomfort and vulnerability associated with the absence of certainty.

The Presumed Non-adaptability of 3IR Engineers

Of the 12 participants, 10 consider themselves more adaptable when compared with the other 3IR engineers. When providing reasons for the presumed non-adaptablity of 3IR engineers, six out of the 12 participants mentioned that they believe age is a factor that can influence one's adaptability. All six participants shared the same observation that the older one gets, the more one tends to be set in their ways, have a greater propensity to resist change, and be less adaptable. For example, Barnard maintains that: 'My experience is some of the older guys are probably less adaptable'. Barnard continues by saying, 'I wouldn'*t say they can*'*t adapt, but they*'*re probably more resistant to change than maybe some of the younger guys that are still willing to experiment*'. Prince (2019) argues that as we get older, we develop behavioural scripts, which can stifle our ability to adapt and contribute to people not questioning whether there are faster and more efficient ways of doing something. The participants believe that 3IR engineers, in particular older engineers, are non-adaptable compared with other 3IR engineers. Age is not directly related to adaptability but rather the length of tenure producing behavioural scripts, which may cause engineers to become set in their ways. It is important to emphasise that these claims regarding 3IR engineers' adaptability are derived from participants' perceptions and observations. To remain adaptable, the 4IR ambidextrous engineer needs to continuously re-evaluate their behavioural scripts, learn to identify and discard the unsuitable and outdated scripts, and replace them with new ones that are current and efficient.

Being a 4IR Ambidextrous Engineer: The Adaptability Machine

The *Adaptability Machine*, as depicted in Figure 1, provides a framework to discuss intrapersonal and interpersonal skills and environments that are conducive to coping with and adapting to any disruptions faced during 4IR. The adaptability gear is represented by a large ring gear that encapsulates all the other gears, forming the internal adaptability components. The adaptability gear keeps all the internal components together and allows all the internal gears to work and mesh with one another.

The self-awareness central gear

Similar to Prince (2019), who claims that self-awareness is the cornerstone of all behavioural change, this article proposes that self-awareness is the adaptability machine's central 'gear' that drives the self, social and environment attribute areas. In addition to the attribute gears spinning about their

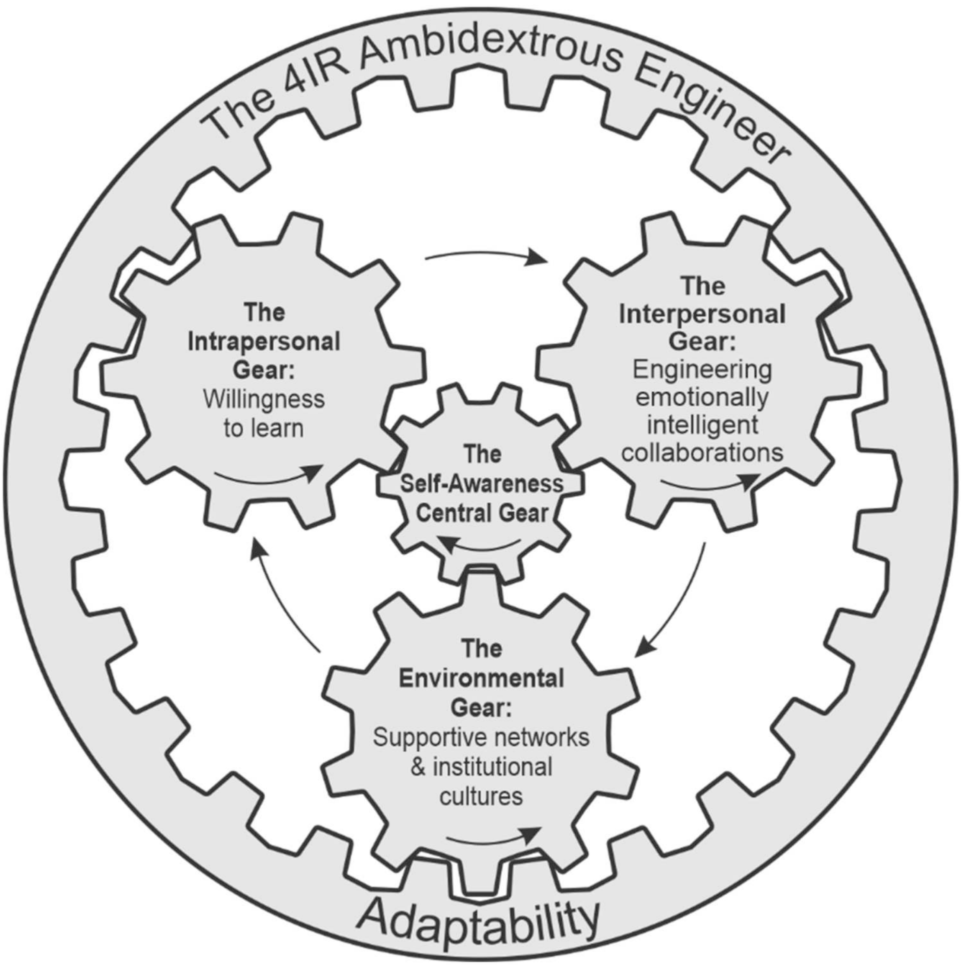

Figure 1. The adaptability machine.
Note: Figure generated by the researcher.

central axis, the adaptability gear guides the attribute gears around the self-awareness gear in an orbital motion. This rotation and orbital translation of mechanical gears are analogous to the inner workings of a 4IR ambidextrous engineer that is both self-aware and highly adaptable.

For instance, Anna highlights the importance of empathy in a leader, and Thato and Nicci both mention that emotional intelligence is required for adaptability. Similarly, Ed proposes that how engineers deal with people may be as important as their technical skills:

> Ed: It's not our technical ability that is allowing us to succeed in our careers; it's how we're dealing with people, and it's understanding. It's from a self-awareness point; it's getting yourself to understand that.

After Alfred left the engineering field and entered the business consulting industry, he realised how non-adaptable he was when practising as an engineer:

> Alfred: And one of the big challenges for me in changing and moving outside of engineering into more strategic consulting and business consulting, was becoming more flexible and becoming more adaptable.

Alfred continues by stating that most engineers are unaware that they are not adaptable, 'many engineers don't realise themselves that they are non-adaptive, and so are stuck in their ways, it's a blind spot for engineers'. Furthermore, he suggests that introspection and self-awareness are necessary to be adaptable.

> Alfred: To be adaptable you have to be aware of your blind spots, and I think not everyone sort of reflects on their behaviour and performance … if you don't reflect and think, hey actually those guys had a point, and I was sticking quite hard to my guns on a certain thing. If you don't reflect, you never learn from that and think that there are other ways to do things, there's another way to adapt to the situation … So, introspection is the first thing; it's finding out where your shortcomings are and thinking the next time I'm faced with that situation, how do I adapt my own behaviour to get a better outcome. So, I think that introspection and awareness, self-awareness.

As Zhang et al. (2018) argue, the aspect of recognition (or awareness) must first be attained before one can focus on regulation. Being aware and appreciating differing personality traits not only provides insight into one's traits (self-awareness), but also the personality traits of others (social awareness).

The intrapersonal gear: willingness to learn

For the intrapersonal gear, willingness to learn is the anchoring behaviour, supported by the mindsets of humility, curiosity and resilience. Of all the adaptability attributes, willingness to learn was mentioned the most, with nine of the 12 participants highlighting that willingness to learn is an important attribute required to be adaptable.

> Leo: the willingness to be constantly learning … so just being willing to learn, you know, yeah, accept the fact that you don't know everything, and you dive into something out into the unknown again, and just be willing to learn.

Ames (1990) suggests that a willingness to learn is a critical outcome of teaching in which students learn to value the process of learning itself and ultimately become lifelong learners. The participants mentioned that an attribute which aids willingness to learn is humility. Thato claims that 'the biggest personality trait one must have is humility [which is] a bit of a challenge when it comes to subject matter experts'. Thato goes on to explain that 'you can't adapt if you can't humble yourself to say, I don't know, I'm going to learn, I'm going to ask somebody else, who perhaps is even younger than me'.

A study by Trinh (2019) investigated healthcare professionals' adaptability compared to their expertise and humility. The study findings showed that humility was the more consistent moderator and that the healthcare professionals with high reported levels of humility and expertise were associated with high levels of adaptability. In contrast, healthcare professionals with low levels of humility and high levels of expertise were associated with low levels of adaptability. Similar to humility, the findings suggest that curiosity also encourages a willingness to learn. For instance, Leo states, 'if you're not curious about something new and different and interesting, you know, you're not going to be willing to adapt and learn'. Curiosity's primary functions are exploring and delving into situations that may result in new information and experiences. In the long term, consistently satisfying one's curiosity expands knowledge, develops intellectual and creative skills, and builds and strengthens social relationships (Kashdan et al., 2018).

Furthermore, being adaptable involves taking risks that inevitably result in failures and mistakes; having resilience allows one to accept that mistakes were made, learn from the mistakes, and move on. As Gugu explains, 'no matter how resilient the system is, there are always limits and the testing of those limits, it's okay for the limits to get tested because otherwise, you don't know at what point you are going to be overwhelmed'. Accordingly, a willingness to learn, supported by humility, curiosity and resilience, will aid the 4IR ambidextrous engineer to cope with disruptions brought about by 4IR and COVID-19.

The interpersonal gear: engineering emotionally intelligent collaborations

For the interpersonal gear, collaboration and communication are the anchoring behaviours that are developed through empathy and emotional intelligence. Alfred states that engineers communicate well with other engineers but struggle to communicate with people who are not engineers:

> Alfred: Engineers have a very structured approach, they lean a lot, heavily on their technical knowledge. They tend to lean less on the more emotional side that many other people rely on. So, building repertoire, engaging people in a social setting, on topics that are not engineering related, building those types of relationships, talking about communicating finances is not something that engineers are very strong at.

Leo adds that engineers are 'pushed out of their comfort zone' when working with a group of people to solve problems. However, Leo acknowledges that 'being pushed out of your comfort zone will lead to adaptability and creativity'.

Alex and Colin hold similar views on engineers' collaboration skills:

> Alex: Engineers are sometimes a problem in terms of trying to deal with other people.
>
> Colin: Engineers generally can't work well with other people who are not engineers.

The findings suggest that engineers understandably rely heavily on their technical knowledge and therefore communicate well with others with similar technical knowledge. However, they struggle to communicate with people who rely on other skills, such as creativity and social interaction. Innovation now demands that people work together, and as a result, crucial job requirements at any company are intrapersonal and interpersonal skills in leadership, humility, collaboration, adaptability and the desire to learn, unlearn and re-learn (Friedman, 2014). This study suggests that the 4IR ambidextrous engineer needs to learn how to adapt their communication style depending on the audience being addressed.

Anna adds that engineers may lack communication skills because they need to develop empathy:

> Anna: I don't know how to put it, but I want to say that we need to have this human side of it, like the soft side of us. You know, I don't know how to put it, like we always want to look at technical stuff and concentrate on that. That's it, we don't want to deal with emotional, yes, emotional things. You know, most of the engineers that I work with, we don't want to talk about personal things, we don't want to talk about empathy and all these other emotions … so I think we need to work on both, you know, be technical and also have the soft side of things. I don't know what the word for it.

Anna goes on to emphasise the importance of developing one's relational emotional intelligence:

> Anna: Having that empathy to understand other people's perspectives, you know, yeah, so it's … having that emotional intelligence. Yeah, that's the word that I was looking for. Yeah, but we don't have that. As engineers, we are not taught those kinds of things, we just work on technical, how to solve technical skills, how to solve technical problems and it's not always the same because machines don't talk back to us.

Thato shared Anna's sentiments about having the emotional intelligence to better communicate with each other and handle criticism:

> Thato: developing your emotional quotient, like emotional intelligence, which for me, is one of the biggest parts that need to be developed. If you're going to work in project teams … I think that is a big development area for engineers. We're in a world where you're no longer a design engineer sitting at the back of your computer and you don't have any interaction with the client or the end user … so you need that emotional intelligence to handle criticism.

These findings suggest that developing emotional intelligence could be a means for the 4IR ambidextrous engineer to better collaborate with others and be more adaptable. Emotional intelligence is developed through experience, openness, willingness to learn and self-awareness (Prince, 2019). Mayer et al. (2011) state that emotionally intelligent individuals are proficient at perceiving, understanding and managing emotions. A key to having emotional intelligence is being empathetic. Anna states that having empathy is 'to understand other people'*s perspectives*'. Accordingly, the 4IR ambidextrous engineer needs to effectively collaborate with others and be able to adapt their communication style appropriately. Having empathy and emotional intelligence will aid 4IR ambidextrous engineers in developing successful and dynamic working relationships while enhancing collaboration with others.

The environmental gear: supportive networks and institutional cultures

For the environmental gear, mastering the skills and attributes discussed in the intrapersonal and interpersonal gears may not be enough to become adaptable, as one's environment needs to be conducive to promoting adaptability. The findings suggest that institutional cultures that promote adaptability in turbulent environments are created through mentorship, leadership, supportive networks, and where employees are motivated to learn from their mistakes. For example, Gugu states that one's environment dictates the need to be adaptable because people are often not in control of the environment in which they operate and work: 'when the world itself changes … you find yourself in a situation whereby you no longer have a choice, but you have to reconsider your ways of thinking and your ways of doing things'.

McKeown (2012) warns that stable environments are only an illusion of stability. While operating in these turbulent environments, Peter and Gugu allude to how supportive networks, the freedom to learn from one's mistakes and an organisation's tolerance for ambiguity promote an institutional culture of adaptability. Resilient individuals tend to have strong social networks, as these people can lean on their networks for support in times of hardship. For organisations and employees to be adaptable, organisations must display a tolerance for ambiguity (Prince, 2019).

Trying new things, irrespective of whether the solution or response is correct or optimal, is essential for being adaptable, as demonstrated in the excerpt below:

> Gugu: If you know that it's okay to make mistakes, I think that can actually it can be very good for people because it gives one that confidence to know that I can try this thing, I tried it.

The statements above by Peter and Gugu correspond to the work done by Loehr, where she highlights that adaptability is a skill that corporations need to develop and nurture. Ed and Leo emphasise the importance of mentorship and leadership in creating an institutional culture conducive to adaptability.

> Ed: I feel that it's [adaptability] very mentor-driven. So, if I look at the mentors that I had, they were very stuck in their ways. And it led me to a specific direction in which I wanted to go, similar to them. However,

> when adaptive changes started coming through, they weren't willing to move across. And it meant that I had to change my mindset quite a bit.

Leo adds that if organisations 'don't come through on promises, it then has negative effects on people, your people then lose motivation. They become less interested, and they're just not willing to be creative or do anything interesting. If they know that there's almost no point, you know, if they're not going to get supported'. Accordingly, a 4IR ambidextrous engineer thrives in institutional cultures where they are motivated to learn from their mistakes and are supported by mentors, leaders and networks.

Becoming a 4IR Ambidextrous Engineer: Teaching and Learning Adaptability

There was a clear consensus among all participants working in academia and industry that teaching intrapersonal and interpersonal skills to engineering students at higher education institutions to develop adaptability would be beneficial. All participants working in the engineering industry felt that it was necessary to change engineering curricula to teach adaptability. However, half of the participants working in academia displayed apprehension about changing engineering curricula. For example, Peter indicated that he would not add new courses but modify an existing course: 'I think not really to introduce a new subject, we can maybe restructure some of the subjects that we have'. Nicci stated that adding a new course would be difficult, as 'obviously, first we have to deliver the content'. Nicci highlights that delivering engineering content has to remain the focus of engineering faculties, as minimal time is available to cover the engineering content as required by accreditation and regulatory bodies such as the Engineering Council of South Africa.

Gugu argued that there was a place for teaching adaptability and awareness skills within engineering curricula. However, she mentioned that she experienced resistance at her university in trying to implement the teaching of her resilience course:

> Gugu: I was talking about the concept of resilience that I teach, or at least try to teach that concept to fourth-year students. So, and I can tell you that, for example, even when you are organising seminars at the level of the school, there are still colleagues and students, even as students that retain this perception that this is a nice-to-have. These are nice ways to see the world; it's nice to think like this, but that is not a necessity. We don't need to think like this to survive. So I do think that in South Africa, you see that a bit more than in other areas.

The participants expressed numerous opinions, ranging from teaching these skills in the first year of study to the final year of study to post-graduate modules. Many suggestions were given by the participants, ranging from (1) introducing intrapersonal and interpersonal skill courses such as communication, stress management and mental wellness to (2) having engineering students select a course outside of the engineering faculty and (3) introducing business and finance courses into engineering curricula. For example, Colin and Gugu thought that having engineering students do subjects outside the engineering faculty would increase their adaptability by forcing engineering students to work and communicate with non-engineering students.

> Colin: People [could] do one course out of engineering, whether it's either humanities or you are at commercial. Well, now you are interacting with different people, because engineers generally can't work well with other people who are not engineers, which means we can't even adapt to other teams, and in life, you work among people. So, once you are taken out of your comfort zone and forced to do your course with other people, you're thinking that that course will change you.

Alex, Barnard and Alfred, all working in industry, shared strong views that 3IR engineers usually have a gaping lack of knowledge in the commercial aspects of business, which negatively affects their adaptability. These participants mentioned that finance and commerce courses should be included in engineering curricula. Similarly, Leo claims that universities teach skills students require at the beginning of their careers and neglect to include the skills needed throughout an engineer's career.

> Leo: So, if you look at a lot of what universities are trying to do, they think of what we must do to equip students with what they are going to need on day one, when they start their job. Okay, and that's what they think, that's what they often think about. To me, it's like, no, that's completely wrong. You need to not be thinking about what they need on day one, you need to be thinking about what skills they will need for the next 40 years. Okay, and that changes the perspective quite dramatically. And, I really don't believe that a lot of universities have thought about it in that way.

In recommending the skills that higher education should include, Leo refers to the Future of Jobs reports that the WEF has published.

> Leo: So, the kind of skills needed, okay. And, you know, I mean, the WEF has all of these sorts of reports that they do, the future of jobs and all of these things and one of the latest ones that I saw, I think the 2021, four of the top 10 skills that are needed are problem-solving, then there's critical thinking. Yeah, so it's mostly problem-solving, critical thinking and thinking about technologies in the future.

Leo concludes that the skills recommended by the WEF were technical in the past, but in recent years, technical skills have been merged with people skills. Leo referred to the amalgamation of these two types of skills as people-technical skills.

> Leo: So, they've, in the previous reports, they kind of had very separate sorts of human and technical skills. But what they've somehow managed to do is kind of merge them in some way. So, they're, you know, technical skills, but people's technical skills.

The introduction of non-technical skills during an engineer's training may significantly influence the adaptability of engineers. For example, the University of Illinois Urbana-Champaign has introduced an emotional intelligence course called Engineering Emotional Intelligence, which intends to improve the engineering undergraduate students' human behaviour skills and capabilities (Crowley et al., 2001).

Conclusion

Although researchers emphasise the central role of adaptability in coping with 4IR disruptions, little guidance is provided on how to become adaptable. Therefore, this article fills the research gap, adds to existing literature and makes a theoretical contribution by depicting how one prepares to become a 4IR ambidextrous engineer in South Africa. Based on the findings, we proposed the framework of the *Adaptability Machine*, consisting of four internal gears which explain the mechanisms involved in being a 4IR Ambidextrous Engineer. Self-awareness is the adaptability machine's central gear that drives the intrapersonal, interpersonal and environmental gears. The intrapersonal gear entails a willingness to learn, supported by humility, curiosity and resilience that aid 4IR ambidextrous engineers to cope with disruptions brought about by 4IR and COVID-19. The interpersonal gear emphasises emotional intelligence, which will aid 4IR ambidextrous engineers to communicate and collaborate with others effectively. Regarding the environmental gear, 4IR ambidextrous engineers thrive in institutional cultures where they are motivated to learn from their mistakes and supported by mentors, leaders and networks. Accordingly, higher education institutions could modify engineering curricula to include self-awareness, intrapersonal, interpersonal, leadership, as well as business and financial skills that would assist engineering students in becoming 4IR ambidextrous engineers. An illustrative example is the University of Illinois Urbana-Champaign's introduction of Engineering Emotional Intelligence, a course designed to develop engineering students' emotional intelligence (Crowley et al., 2001). The findings suggest that these skills could be introduced during the first or final year of study, or within a postgraduate module, by allowing engineering students to enrol in courses offered by other faculties. Such opportunities would enable them to collaborate and communicate with students from other faculties.

Limitations and Implications for Future Research

A limitation of this study is that the data are not sufficiently detailed to inform comprehensive curriculum design. This study is limited in that the positioning of the Adaptability Machine within established adaptability frameworks, such as Ployhart and Bliese's I-ADAPT-M (2006), falls beyond the scope of this article. Further research could compare the Adaptability Machine with relevant models to evaluate whether it builds upon and/or diverges from established adaptability frameworks. Another limitation of this study is the sample bias toward successful or senior engineering professionals, which may affect the extent to which the findings on engineer adaptability can be generalised.

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No potential conflict of interest was reported by the author(s).

Availability of Data and Materials

The interview dataset generated and analysed during the current study is not publicly available to preserve participants' privacy and confidentiality.

ORCID

Luigi Liccardo http://orcid.org/0009-0007-8968-5358
Sabrina Liccardo http://orcid.org/0000-0002-1443-7743
Jenika Gobind http://orcid.org/0000-0002-0452-6531

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