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Impact of the Fourth Industrial Revolution on Engineering Technology Education Programmes

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EXECUTIVE SUMMARY

The rapid, exponential fusion of technologies that profoundly disrupts virtually all industries and processes is commonly described as the Fourth Industrial Revolution (4IR). The engineering sector is overdue for radical transformation, but how can we ensure current and future South African engineering technologists and technicians graduates are sufficiently knowledgeable and skilled to cope with the challenges they will face?

This study sought to identify the level of adoption of 4IR technologies into South African engineering technology education and subsequently evaluate the impact of 4IR technologies on achieving the required skills and competencies for technologists' and technicians' roles and engineering technology education.

The study undertook an extensive literature review to identify engineering technologists' and technicians' required skills and competencies in the 4IR era and the most appropriate 4IR technologies to be used in engineering technology education and incorporated into the engineering technology education curriculum. In addition, a questionnaire survey was conducted to gather the necessary data from engineering technology experts, educators and students.

The collected data was analysed using descriptive and inferential statistics to determine the impact of 4IR technologies on South African engineering technology education and the required skills and competencies for engineering technologies and technicians.

While the study verified the high impact of 4IR technology on engineering technology education (both on theoretical and practical subjects) and achieving the required skills and competencies for technologists and technicians, the level of adoption of these technologies in South African engineering technology universities is significantly low.

The studies found a low level of adoption of 4IR technologies in engineering technology education in South Africa due to limited awareness of educators and lecturers about the critical role of applying innovative technologies in engineering technology in the 4IR era.

The study concluded that these low levels of adoption and awareness could result from the low number of registered lecturers with ECSA as professional engineers.

Therefore, the study recommended enhancing the level of adoption of 4IR technologies in South African engineering technology education and South African universities and ECSA should provide a special mechanism to register all engineering lecturers with ECSA.

Furthermore, the ECSA should consider adopting 4IR technologies in teaching and learning pedagogy (including integrating into the curriculum, teaching methods and assessment) as one of the accreditations of engineering technology and technician programmes of South African universities.

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ABBREVIATIONS

4IR	Fourth Industrial Revolution
AAC	academic advisory committees
ASCE	American Society of Civil Engineers
CPD	Continuing Professional Development
ECSA	Engineering Council of South Africa
ET	Engineering Technology
IoT	Internet of Things
Pr Cert Eng	Professional Certificated Engineer
Pr Eng	Professional Engineer
Pr Tech Eng	Professional Engineering Technologist
Pr Techni Eng	Professional Engineering Technician
RII	Relative Importance Index

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1. INTRODUCTION

Technology has been the driver of different human endeavours. With different dispensations comes a new or set of new technologies that humans have used to make their lives easier, while at the same time trying to enhance and perfect such technologies. Education is among such areas of human activities in which technology has been used. This report aims to examine the impact of technologies associated with the Fourth Industrial Revolution (4IR), specifically, the impact of 4IR-related technologies on Engineering Technology and Technical education.

2. BACKGROUND

This section of the report documents related background and useful information to aid in understanding the approach of this work and the corresponding findings that lead to the conclusions drawn regarding the impact of 4IR technologies on Engineering Technology and Technical education, using South Africa Universities of technology as a case study.

2.1 Evolution of education

The educational system has evolved over the years, some of which evolution has been driven by emerging technologies. The various versions of these evolutions are illustrated in Figure 1. As shown in the figure, Education 1.0, characterised by systems mechanisation, came into being in the late 18th century, lasting until the late 19th century. In the early 20th century, the education system evolved into Education 2.0. During this period, mass production and industrialisation abounded, with the emergence of electricity, and electronic devices such printers, calculators and computers were introduced into the education system. Subsequent to this came Education 3.0 towards the end of the 20th century. This era brought computerisation of what used to be executed manually, automation and other innovations, which enhanced teaching and learning processes by making possible the use of multiple resources such as multimedia, online tools, and virtual laboratories.

With the advent of the 4IR, different innovations were introduced into the education system, and the pedagogical techniques in particular sum up what is currently called Education 4.0.

	Education 1.0	Education 2.0	Education 3.0	Education 4.0
Period	Late 18th Century	Early 20th Century	Late 20th Century	Present
Philosophy	Essentialism, behaviorism, and instructivism	Andragogical, constructivist	Heutagogical, connectivist	Heutagogical, peeragogical and cybergogical
Educator role	Sage	Guide, information source	Orchestrator, curator and collaborator	Mentor, coach, collaborator, reference
Student role	Largely passive	Emerging active "owning of the knowledge"	Active, "Knowledge ownership", initial independence	Active, high independence, trajectory designer
Approach	Teacher-centered	Peer assessment encouraged, high teacher importance	Co-constructed, first student-centered	Mostly student-centered
Learning outcome	Grades, graduation degree	License to professional practicing	Prepared for practice and scenario analysis	Training of key competencies both soft and hard
Enablers	Mechanical printing, graphite pencil, ballpoint pen, typewriter	First computers, electronic devices and calculators	Computers and widespread use of the internet	ICTs tools and platforms powered by IoT
Information source	Standard texts	Adopted texts and open-source material (physical)	Texts, case studies, second hand experience	Based on online sources
Facilities	Universities / classrooms	Blended laboratories and classrooms	Blended and flexible physical shared spaces	Cyber and physical spaces both shared and individual
Industrial technology	Mechanical systems, steam powered	Mass production, industrialization and electricity	Internet access, automatization and control	Connectivity, digitalization and virtualization

Figure 1: Evolution of Education 1.0 to Education 4.0 [1]

2.2 Industrial revolution

The first industrial revolution commenced in England in the late 18th century when related industrial production started, which sped up socio-economic changes in England. During this period, coal, water and steam were employed with consequent large-scale manufacturing of goods and urban densification. This evolution led educational institutions into what is called a "New Education", where new types of educational curricula offering various degree options and novel educational programmes were introduced. Subsequent to this came the second industrial revolution which brought the division of labour and the reduction of marginal costs into the manufacturing of goods.

During this period, electricity was invented, and the emergence of internal combustion engines led to automobiles. This revolution made educational opportunity accessible to the industrial classes, resulting in a "*new economy*" enabled education that was "*created for a steady stream of newly trained technicians and engineers trained in the practical avocations of life*" [2]. According to [3], the third industrial revolution emerged with the information age and automation. While society at large has benefitted from economies of scale to create a largely middle-class society, the dominating models in the 19th and early 20th centuries have constructed the welfare state. The advent of computers and digital systems during this period enabled new ways of processing and sharing information. In terms of its impact on the education system, this era prompted migration towards online education, which in turn has extended access to university education to many people who previously were unable to take courses of interest or attend universities of choice. The third industrial revolution made access to information quick and free, shifting the focus toward active learning pedagogies that place a premium on collaboration within diverse teams in a project-based and peer learning environment.

Like the industrial revolutions before it, the 4IR brings incredible opportunities for individuals, industries and nations. Artificial intelligence, the Internet of Things (Iot) and the potential of quantum computing promise better optimisation of systems. According to [4], the 4IR is bringing about the possibility of a new energy, communication and logistics matrix that has the potential to connect distant locations with a supply of products or services, while dynamically interconnecting human activities with machines. The impact of this revolution is such that it puts a premium on adaptability in learning and thinking. This implies that the shelf life of the present-day educational skillset has become increasingly short, requiring the future workforce in the classrooms to update their knowledge and proficiencies to meet the demands of new technologies and industries [5] and [6]. It is expected that substantial amendments will be made to the educational curriculum to allow students to rapidly develop in emerging disciplines like artificial intelligence, robotics, genomics, data science, and nanomaterials. Figure 2 depicts these industrial revolutions from the first to fourth industrial revolutions.

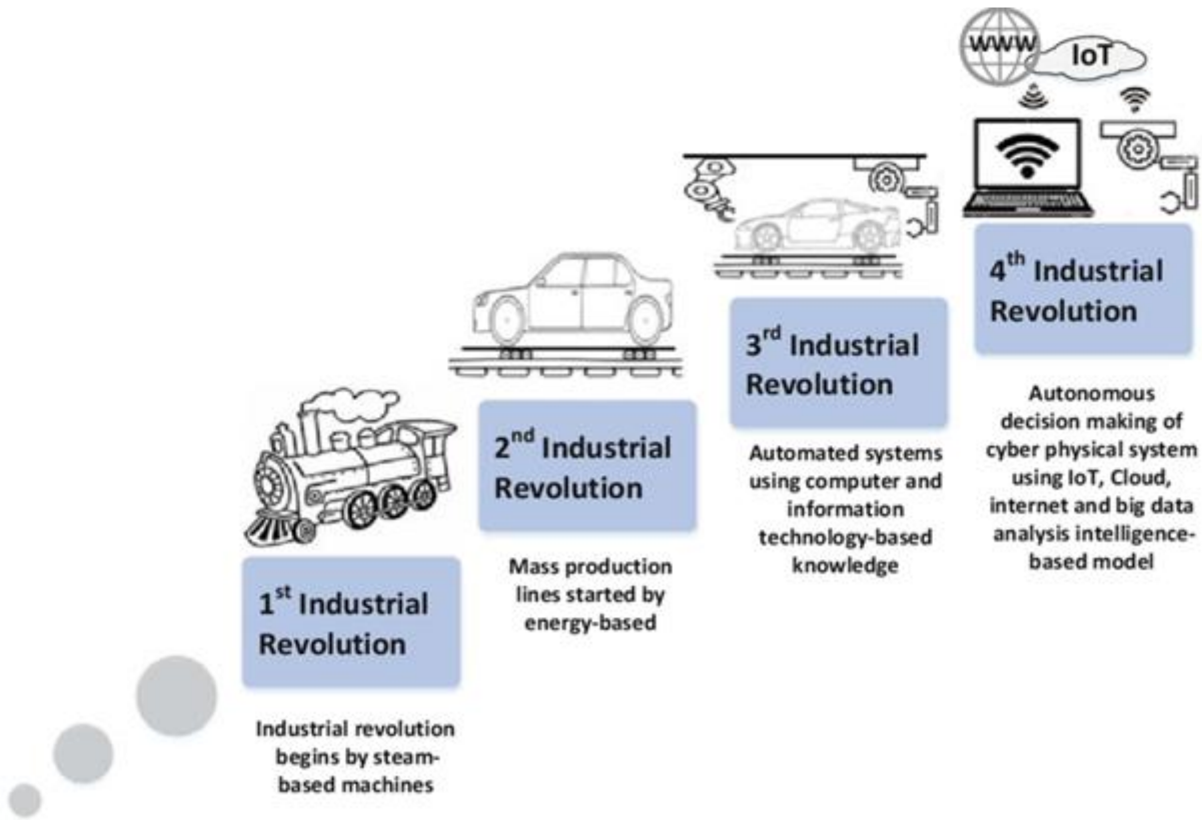

Figure 2: Industrial revolution from 1st Industrial revolution to 4IR [7]

2.3 Description of engineering and engineering technology

Engineering is the practical application of scientific principles in a creative way to design, develop, carry out and build structures, machines, equipment/tools, manufacturing processes and/or intended functions under specified conditions, economically and safely [8]. Engineering is a profession in which knowledge of mathematics and science is applied to solve practical problems to benefit mankind. Engineering technology is concerned with the application of engineering and modern technology rather than its theoretical underpinning [9]. This sentiment was echoed by [10], who indicated that engineering technology describes a field closely related to engineering in which practical application of learned concepts is more emphasised than theoretical knowledge. The American Society of Civil Engineers (ASCE), as quoted below [11] differentiates among engineering professions in terms of the level of authority, using civil engineering as an example:

- A civil engineering professional is qualified to be professionally responsible for engineering work through the exercise of direct control and personal supervision of engineering activities.
- A civil engineering technologist exerts a high level of judgment in the performance of engineering work while working under the direct control and personal supervision of a professional civil engineer.
- A civil engineering technician works under the direct control and personal supervision of a professional civil engineer or the direction of a civil engineering technologist.

The biggest difference between an engineering technology graduate and an engineering graduate is that the former is an implementer and the latter is an innovator.

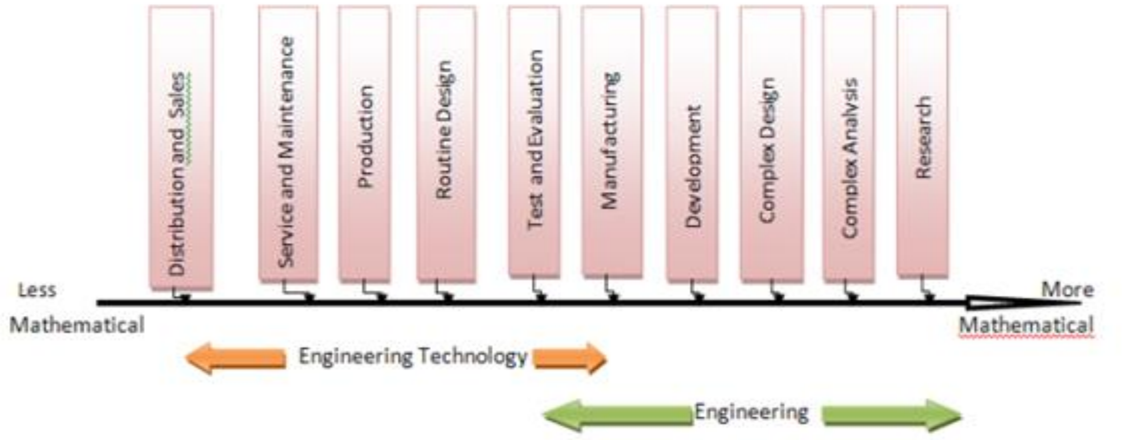

Figure 3: Engineering and Engineering Technology [9]

Figure 3 illustrates that engineering programmes include more mathematics than technology. The topics covered in both programmes are similar, but the knowledge in engineering technology programmes is more applied as opposed to mainly theoretical.

ECSA has grouped engineering professions by professional registrations in terms of their competencies. The four categories are Professional Engineer, Professional Engineering Technologist, Professional Certificated Engineer and Professional Engineering [12].

Table 1 summarises the different categories in terms of the competency required:

Table 1: Competency Standard for Registration in Professional Categories

Category	Level Descriptor
Professional Engineer (Pr Eng)	Solving *complex engineering problems* and performing complex engineering activities
Professional Engineering Technologist (Pr Tech Eng)	Solving *broadly defined engineering problems* and performing broadly defined engineering activities
Professional Certificated Engineer (Pr Cert Eng)	Solving *broadly defined engineering problems* and performing broadly defined engineering activities
Professional Engineering Technician (Pr Techni Eng)	Solving *well-defined engineering problems* and performing well-defined engineering activities

The split for registration for Pr Eng, (Pr Tech Eng), Pr Cert Eng), and Pr Techni Eng was 37%, 11%, 7% and 2%, respectively.

Technologists typically have more specialised skills in a piece of equipment or are involved in design or systems development. They frequently do work that is associated with engineers, although at the more applied end of the engineering spectrum. Technicians, in contrast, are typically involved with equipment installation, maintenance and adjustment [13].

Figure 4: An engineering technology-engineering continuum model

Figure 4 represents an engineering technology-engineering continuum model [14], which illustrates that a number of work-related activities can be performed by both engineers and technologists. These activities include manufacturing and component design as well as development and design.

The study conducted by [15] found an evolving consensus that engineering technology graduates end up as engineers as it is desirable from different perspectives, including the creation of an additional pathway to increase the numbers of engineers. This was confirmed by [16] who agrees that engineering technologists are engineers.

The education sector in South Africa faces a number of challenges to adapt to the 4IR. These challenges include insufficient funding, infrastructure and skills to prepare graduates to participate in the 4IR [17].

2.4 Current use of 4IR technologies in engineering technology and technical education

For educational institutions to take advantage of the accompanying technologies brought by the 4IR, it is essential for the necessary infrastructure to be in place. This entails advanced technology (internet, high-powered machines), data (unstructured, structured, stream, Big, audio, image, text and sensor), institutional configuration (curriculum) and skilled experts (field/practical, non-formal, formal) [18] [19] [20] [21]. The disruptive 4IR-related technologies are powered by the IoT, robotics, nanotechnology, genomics, artificial intelligence, virtual reality, cloud, edge, fog computing and other technologies, as illustrated in Figure 5. The use of these in engineering technology and technical education systems is gradually picking up, as the technologies are relatively new to the educational systems.

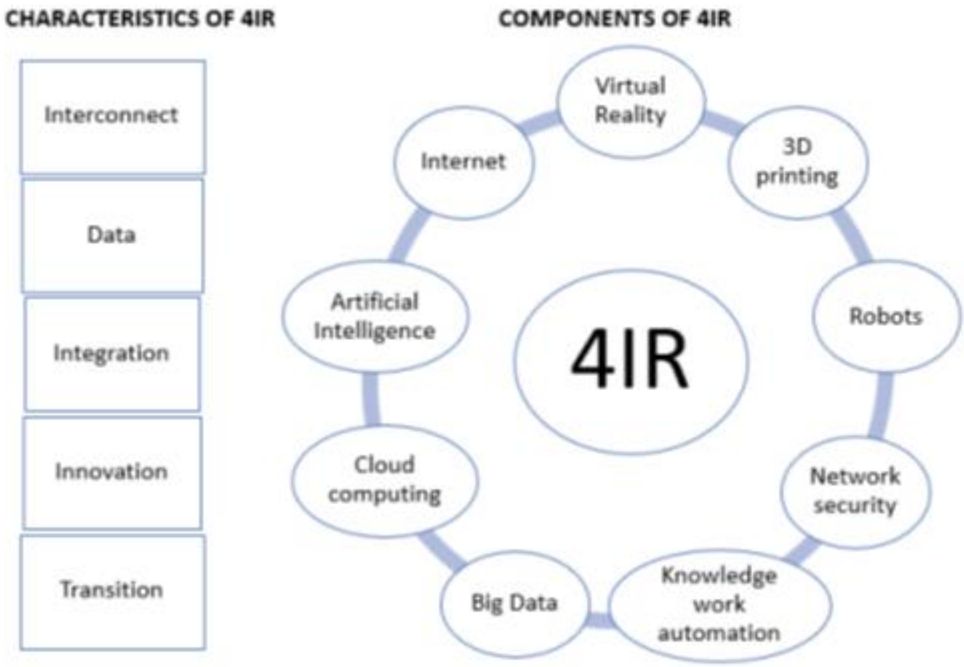

Figure 5: 4IR-related technologies relevant to engineering technology education [22]

2.5 Research questions

This study aims to determine the changes that need to be incorporated into the engineering technology and technical education curricula, modes of teaching delivery and learning, and assessment types, to mention a few, in South African universities to respond to the requirements and opportunities presented by the 4IR.

In most of the literature, the common focus is on the general impact of 4IR on socio-economic welfare, humans and the broader education space, with no specific studies that deliberately focus on the impact of 4IR on engineering technology and technical education. Hence, there is a need to pragmatically study the impact of 4IR on engineering technology and technical education using relevant South Africa universities and industries as the case study. The expectation of this study is to arrive at well-informed recommendations that will bring about enhancement of engineering technology and technical education to meet the rapidly changing skills occasioned by the 4IR and its accompanying technologies.

Hence, the main research question is:

In what ways has the 4IR impacted or will impact engineering technology and technical education in South Africa?

To answer the main question, answers to the following sub-questions are paramount.

(a) What are the required skills and competencies in 4IR era for technologists and technicians?

(b) What are the 4IR technologies necessary for teaching and learning to achieve the required skills and competencies?

(c) What is the level of adoption of 4IR technologies in technology and technical education in South Africa?

3. METHODOLOGY

A convergent, parallel, mixed research design approach was adopted to achieve the research aim and objectives. The convergent, parallel, mixed research utilised a combination of qualitative and quantitative approaches to develop a complete and valid understanding of the impact of 4IR on South African engineering technology education programmes.

The study was initiated by an extant review of existing literature relating to the research concepts, particularly evolution of education and 4IR required new skills and competencies. The relevant 4IR technology used in Education 4.0 and required skills and competencies in the 4IR era for technologists and technicians were identified through a narrative literature review.

The in-depth review of the literature revealed the existing limitations in available research on the impact of 4IR on engineering technology education in particular, especially in South Africa, which helped to establish a theoretical background for the study. Three questionnaires were developed to collect the necessary data from technology and technologist engineer experts, educators and students. The rationale for using questionnaire surveys is to develop a data collection instrument to assist in identifying the level of adoption of 4IR technologies and their impact on various South African engineering technology education programmes.

3.1 Structure of questionnaire survey

The questionnaire instrument was employed to accurately collect required information on the impact of 4IR on the engineering technology education programmes from three groups of professional technicians and technologists higher education educators involved in engineering technology education and finally, technology students across South Africa.

The expert questionnaire (survey) gathered the professional technicians' and technologists' opinions on the new skills and competencies required by graduates and young professionals in the 4IR era, the impacts of 4IR technologies and their optimum level of integration to achieve these new skills and competencies. The lecturers' survey sought to determine the level of adoption of 4IR technologies in teaching and assessment of engineering technology programmes and the improvement of teaching and assessment through using 4IR technologies. The technology students' survey sought to find the level of exposure of students to various 4IR technologies in both theoretical and laboratory subjects of engineering technology programmes and the impact of 4IR technologies on their learning outcomes.

All three survey questionnaires were designed in a uniform structure comprising three main sections, preceded by an introduction to the research and the respondent's consent to participate in the study. The first section asked for the respondents' background information; the second section of the questionnaires included closed-ended questions that asked participants to rate the importance of integrating 4IR technologies in engineering technology education; the third section included open-ended questions.

The quality and suitability of the questionnaires for analysis as a data collection instrument was done through pre-testing the questionnaires with five lecturers who were also registered with ECSA.

3.2 The sample size of the study

The experts' survey was distributed among all registered technicians and technologists with ECSA. While the academics' and students' questionnaires were sent to the following South African engineering technology universities and institutions, namely: Cape Peninsula University of Technology, Central University of Technology, Durban University of Technology, University of Johannesburg, Mangosuthu University of Technology, Tswane University of Technology, University of South Africa, Vaal University of Technology and Walter Sisulu University of Technology. The online survey was created in September 2021 and closed in January 2022, making a survey duration of five months. The 485 completed responses collected at the time of closure of the survey are listed in Table 2.

Table 2: Sample size of questionnaire survey

Survey group	Description	Sample size
Experts	Candidate and professional technologists and technicians registered with ECSA	372
Academics	All educators in South African engineering technology university and institutions	34
Students	All South African engineering technology students	79
Total		**485**

3.3 Method of data analysis

This study adopted the mixed-method research approach in which both qualitative and quantitative data were collected. Therefore, several techniques were employed to analyse and evaluate the collected data to improve the reliability and validity of the research results.

The study employed descriptive and inferential statistical techniques to analyse the quantitative data collected from closed-ended questions. The descriptive statistics employed were percentiles and ranks, while the inferential statistics included Relative Importance Index (RII).

The RII determines the relative importance of research factors based on the rated weight by participants.

$$RII = \frac{\sum \quad (W1 + W2 + \ldots + Wn)}{A \times N}$$

Where:

W = weights given to each factor by the respondents

A = highest weight

N = total number of respondents

To analyse the qualitative data from open-ended questions, the study utilised content analysis, which determined the presence of certain words, themes or concepts, such as *improve learning*, *efficiency*, *etc*, within collected qualitative data from participants.

4. DATA PRESENTATION, ANALYSIS AND DISCUSSION

The study sought to determine the new skill and competencies required in the 4IR era for technologists and technicians, the level of adoption of 4IR technologies in technology and technical education in South Africa and to evaluate the impact of these 4IR technologies on the South African engineering technology programmes.

To achieve these, the study cross-analysed the responses collected from three groups of South African experts, educators and students.

4.1 Quantitative data analysis

In this section, the results of data analysis of quantitative data are presented.

4.1.1 Expert survey

General information collected from expert participants

Tables and figures below present the demographic analysis of the 372 experts who participated in the study.

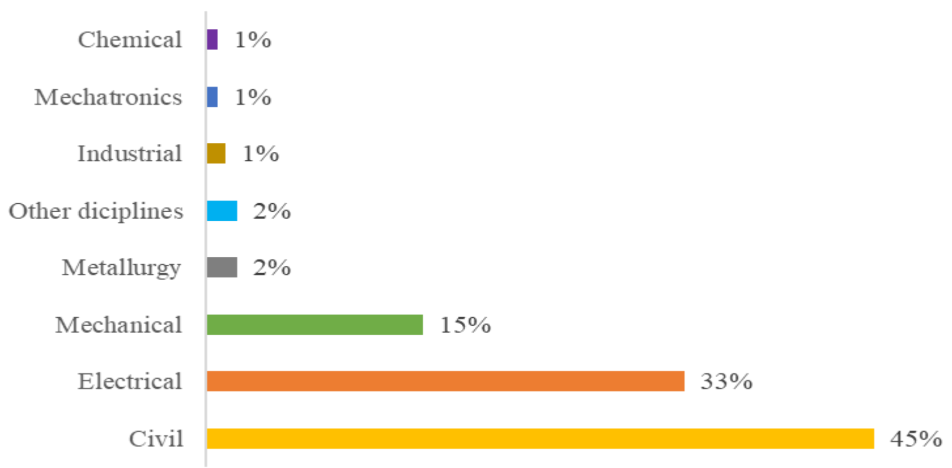

Figure 6: Discipline of experts

As illustrated in Figure 6, experts across all the engineering technology disciplines have contributed their knowledge and professional opinions to this study. However, the majority of the experts (93%) participating in this survey belong to three disciplines civil, electrical and mechanical.

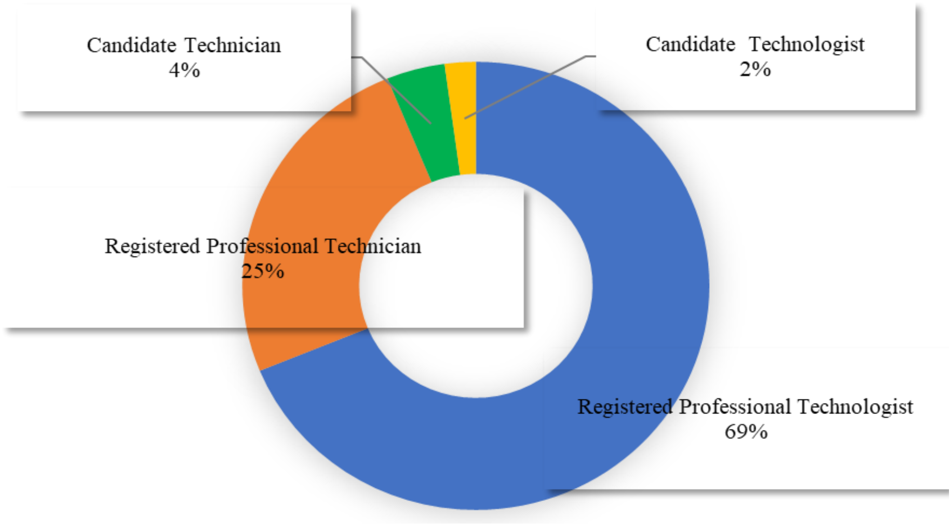

Figure 7: Registration category of experts with ECSA

Of the experts participating in this study, 94% are registered as professional technologists (69%) and professional technicians (25%) with ECSA, while only 6% of expert participants registered with ECSA as a candidate, 4% as Candidate Technician and 2% as Candidate Technologist. This shows that the experts who participated in this study are highly knowledgeable and specialists.

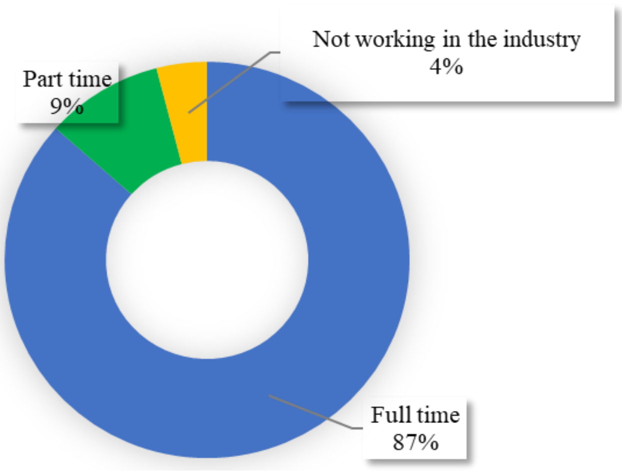

Figure 8: Employment status of experts in the industry

94% of experts work and practise in different disciplines of engineering technology, 87% work full time, and 9% practise part-time. Only 4% of participants are currently not working in the engineering technology industry.

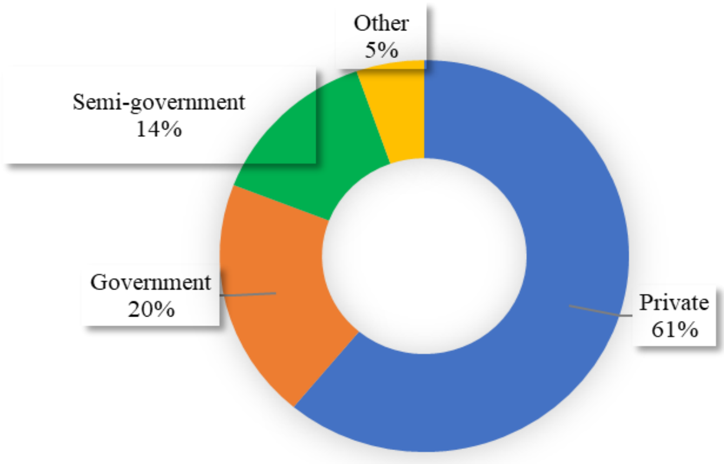

Figure 9: Engineering sectors that experts work in

Most of the experts (61%) work in the private sector, while 34% are employed in government (20%) and semi-government (14%) sectors, with 5% of participants either working in other sectors or retired.

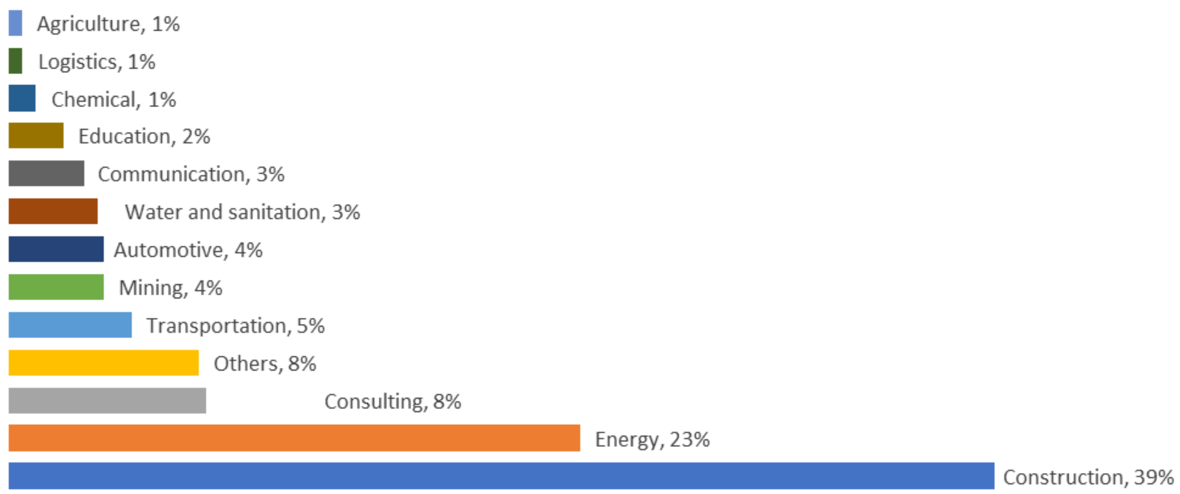

Figure 10: Industries experts are employed in

39% of participants practise in the construction industry since the construction industry is the largest engineering industry in South Africa. Respectively, 23% and 8% of experts work in the energy and engineering consulting industries.

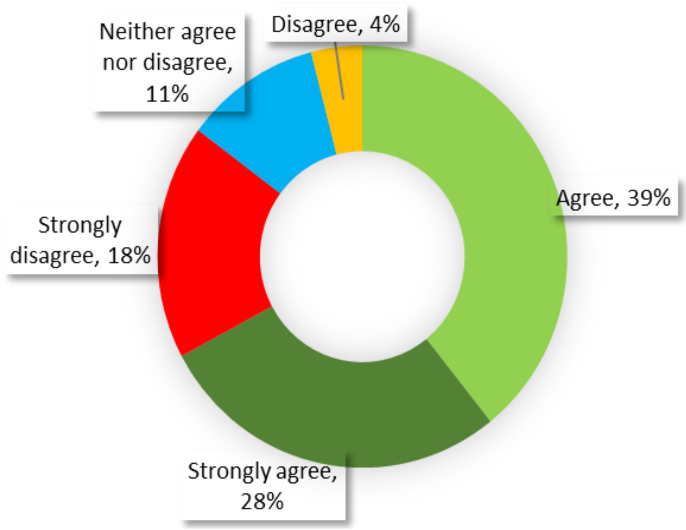

Figure 11: The need to incorporate 4IR technologies into the engineering technology curriculum for various discipline-based applications

As shown in Figure 11, 67% of the experts either strongly agreed (28%) or agreed (39%) on the need to incorporate 4IR technologies into the engineering technology curriculum, while 22% of participants disagreed (4%) or strongly disagreed (18%) with integrating 4IR technologies into the engineering technology curriculum. 11% of experts neither agreed nor disagreed.

The overall agreement score of experts on the need to incorporate 4IR technologies into the engineering technology curriculum is 71 out of 100, which shows a high level of agreement among the disciplines.

Table 3: Importance of engineering skills and competencies in 4IR era

Skill/competency	Score Out of 100	Rank	Importance
Problem solving	77.4	1 Most Important	High
Application of scientific and engineering knowledge	73.7	2	High

Skill/competency	Score Out of 100	Rank	Importance
Engineering design	70.8	3	High
Investigation, experience, experiment and data analysis	68.9	4	High
Engineering method, skills and tools, including Information technology	65.9	5	High
Professional and technical communication	56.6	6	Moderate
Engineering professionalism	53.3	7	Moderate
Independent learning ability	52.3	8	Moderate
Impact of engineering activities	48.6	9	Moderate
Individual, team and multidisciplinary working	46.9	10	Moderate
Engineering management	45.6	11 Least important	Moderate

The importance of engineering skills and competencies clustered in five groups of very high (81-100), high (61-80), moderate (41-60), low (21-40) and very low (0-20) based on the cumulative score out of 100.

Table 3 above shows the five skills and competencies that engineering technologists and technicians require that the experts rate as highly important in the 4IR era. These five engineering skills and competencies are problem-solving; application of scientific and engineering knowledge; engineering design, investigation, experience, experiment and data analysis; and engineering method, skills and tools, including information technology.

The remaining six engineering skills and competencies were perceived as moderately important in the 4IR era by experts. These six engineering skills and competencies are professional and technical communication; engineering professionalism; independent learning ability; impact of engineering activities; individual, team and multidisciplinary working; and Engineering management. These skills are essential in the industry to enhance efficiency and productivity, so acquiring them while studying is also important.

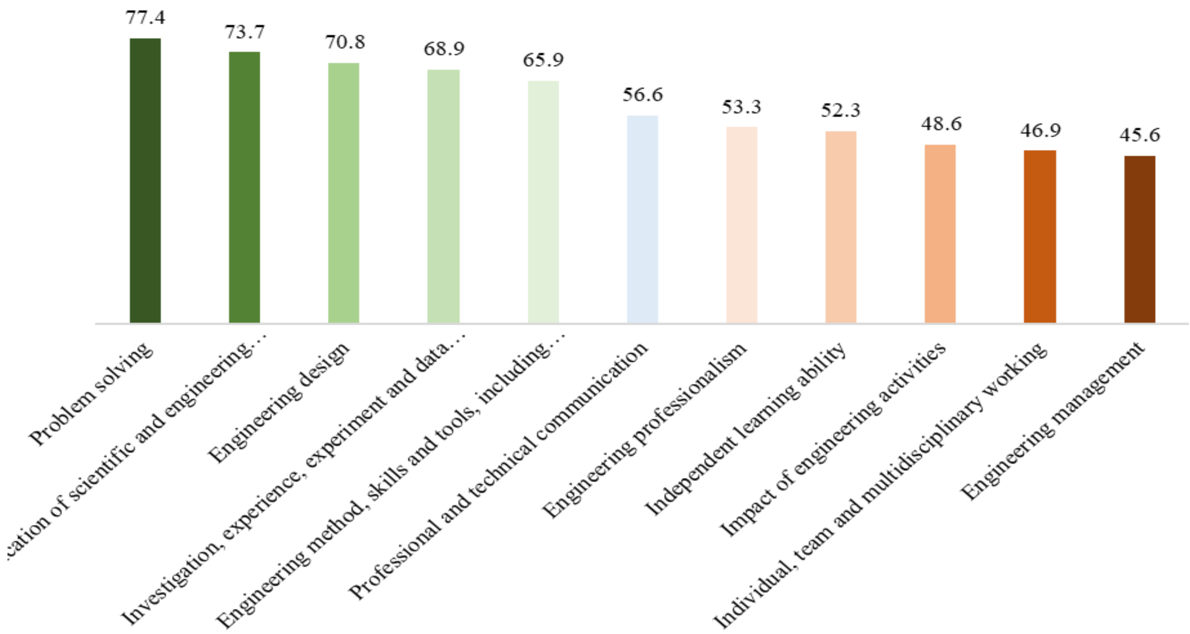

Figure 12: Ranked engineering skills and competencies

Table 4: The impact of 4IR technologies on achieving engineering skills and competencies

Technology	Very high impact	High impact	Moderate impact	Low impact	Very low impact	Level of impact
Data Analytics	31%	32%	26%	6%	5%	83.6 Very high impact
Internet of things	24%	34%	24%	11%	6%	79.6 High impact
Big data	26%	31%	22%	11%	9%	77.6 High impact
Machine learning	24%	30%	24%	15%	8%	75.6 High impact
Artificial intelligence	31%	32%	22%	7%	7%	74.5 High impact
Virtual reality	17%	29%	32%	13%	9%	71.8 High impact
Robotics	37%	37%	18%	5%	3%	70.9 High impact

Technology	Very high impact	High impact	Moderate impact	Low impact	Very low impact	Level of impact
Additive manufacturing/ 3D printers	32%	37%	22%	6%	3%	69.2 High impact
Nano technology	45%	35%	14%	3%	3%	66.5 High impact
Overall impact of 4IR technologies in achieving the required skills and competencies for the technologists' and technicians' roles						74.4 High impact

The level of impact of 4IR technologies on required engineering skills and competencies for technologists and technicians was estimated using RII based on the responses of experts. Consequently, the level of impact is classified in five groups: very high impact (81–100), high impact (61–80), moderate impact (41–60), low impact (21–40) and very low impact (0–20).

As shown in Table 4, experts believe that only data analytics has a very high impact in achieving the required engineering skill and competency, so, all other 4IR technologies are perceived to have a high impact on achieving engineering skills and competency. Moreover, the analysis of the impact of 4IR technology proved that all 4IR technologies have a significant impact on achieving required engineering skills and competencies.

Hence, based on the experts' opinions, the 4IR technologies have a high impact (74.4) on achieving the required skills and competencies for both the technologists and technicians. This indicates that the relevance of 4IR in our contemporary world cannot be overemphasised and if South Africa is to stay on par with the global construction industry, incorporation of 4IR is inevitable.

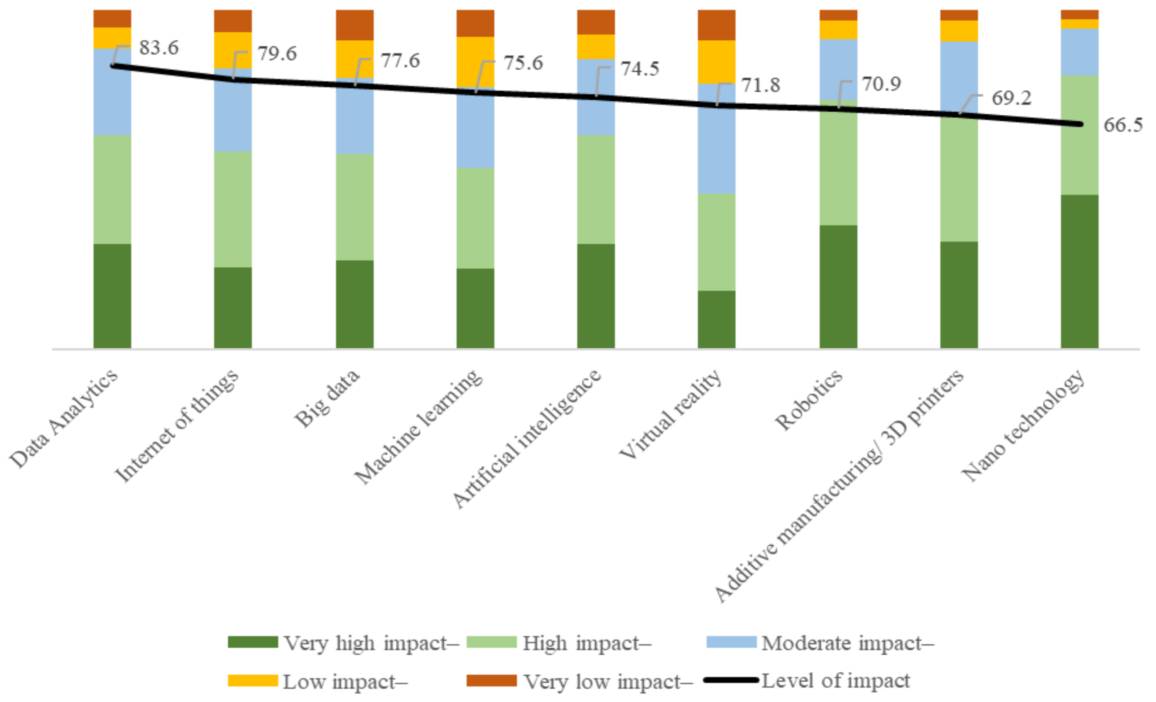

Figure 13: The impact of the 4IR technologies on achieving the engineering skill and competency

Table 5: Optimum level of integrating 4IR technologies into engineering education programmes

Technology	Basic	Intermediate	Advanced	No idea	Optimum level
Data analytics	11%	33%	51%	5%	76.4 Advanced
Internet of things	14%	34%	48%	4%	75.4 Advanced
Machine learning	16%	36%	40%	8%	69.2 Advanced
Artificial intelligence	16%	33%	42%	9%	69.1 Advanced
Big data	14%	41%	37%	8%	69.0 Advanced
Robotics	21%	32%	39%	8%	67.6 Advanced
Virtual reality	22%	38%	33%	8%	67.4 Intermediate

Technology	Basic	Intermediate	Advanced	No idea	Optimum level
Additive manufacturing/ 3D printers	20%	42%	28%	9%	63.4 Intermediate
Nano technology	23%	38%	25%	14%	58.0 Intermediate

The optimum level of integrating 4IR technologies into engineering technology education was calculated based on the professional opinion of experts. The calculated optimum level is classified into three groups advanced (67–100), intermediate (34–66) and basic (0–33).

As shown in Table 5, experts perceive an advanced adoption of data analytics, the IoT, machine learning, artificial intelligence, big data, robotics and virtual reality in engineering technology education. The experts suggested intermediate as the optimum level of adoption of additive manufacturing/3D printers and nanotechnology on South African engineering technology education. Their perceptions are rather conversely proportional to what both lecturers and students reported.

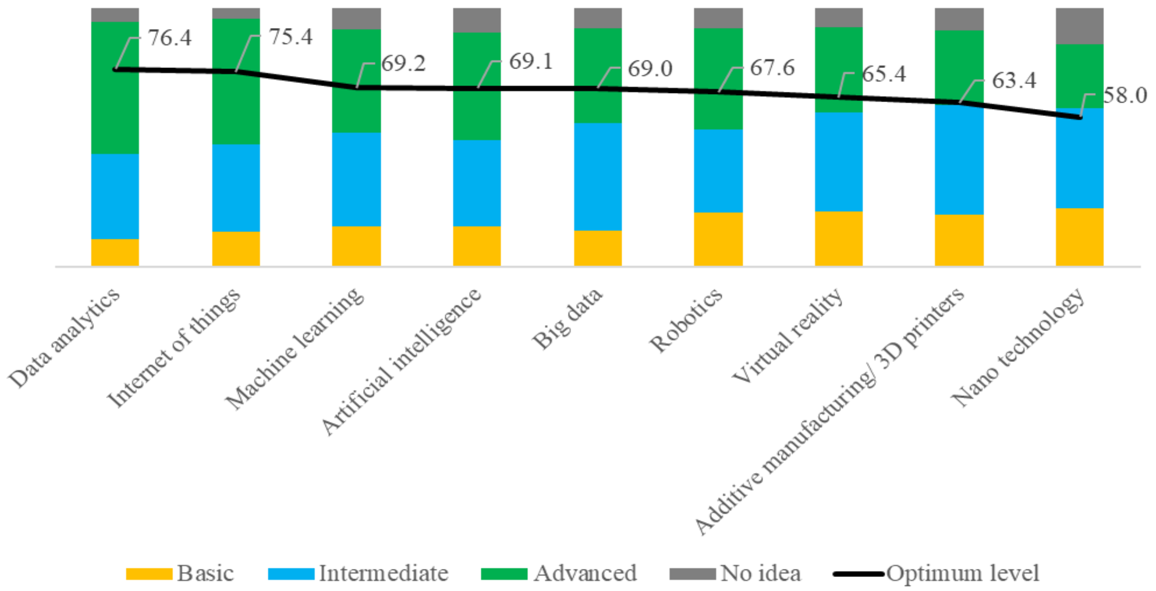

Figure 14: Optimum level of integrating 4IR technologies into engineering education programmes

4.1.2 Lecture survey

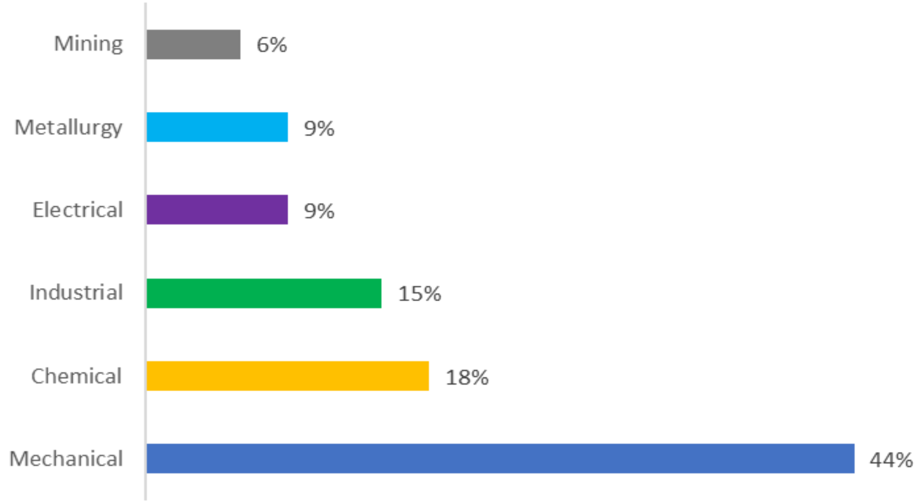

Figure 15: Engineering field that lectures teaching

The majority of higher educators participating in the study teach in the field of mechanical engineering technology (44%) followed by chemical and industrial engineering technology (18% and 15%).

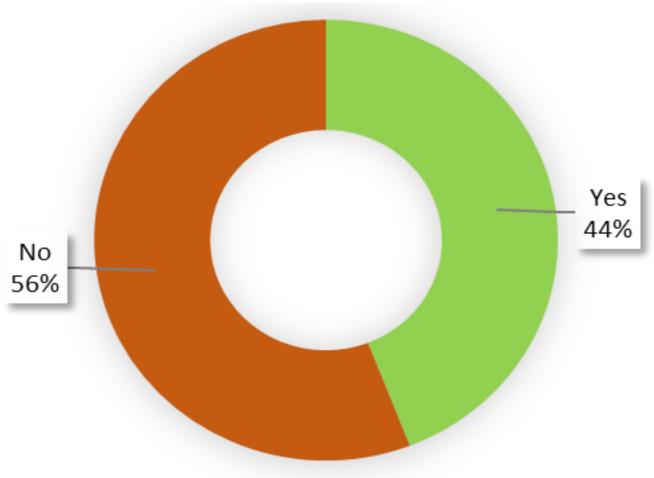

Figure 16: Registration status of lecturers with ECSA

The analysis of the data shows that 56% of lectures are not registered with ECSA and only 44% of lectures are registered with ECSA.

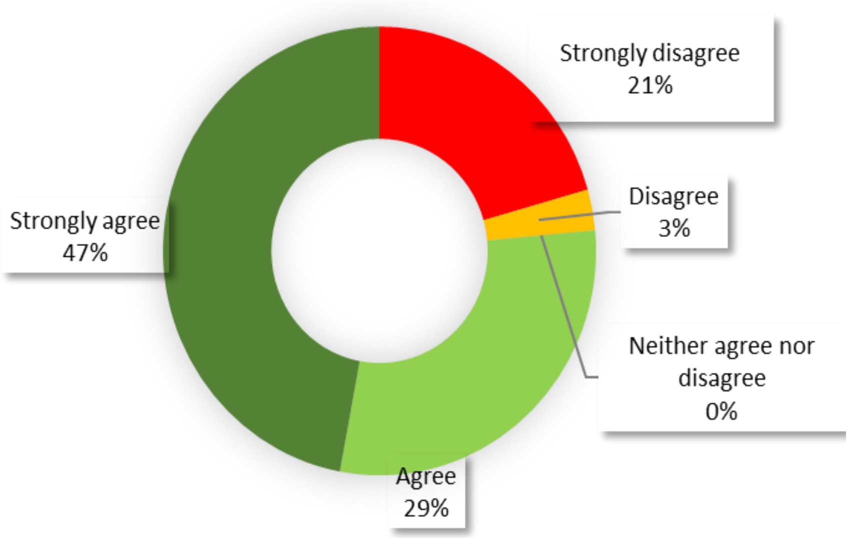

Figure 17: The need to incorporate 4IR technologies into the engineering technology curriculum for various discipline-based applications

As shown in Figure 17 above, 76% of lecturers either strongly agreed (47%) or agreed (29%) on the need to incorporate 4IR technologies into the engineering technology curriculum, while 24% of participants disagreed, of whom (21%) strongly disagreed and (3%) disagreed with integrating 4IR technologies into the engineering technology curriculum.

The 76% overall agreement perception of lecturers seeing a need to incorporate 4IR technologies into the engineering technology curriculum showed a high level of agreement among the lecturers on the importance of 4IR technologies in pedagogical training.

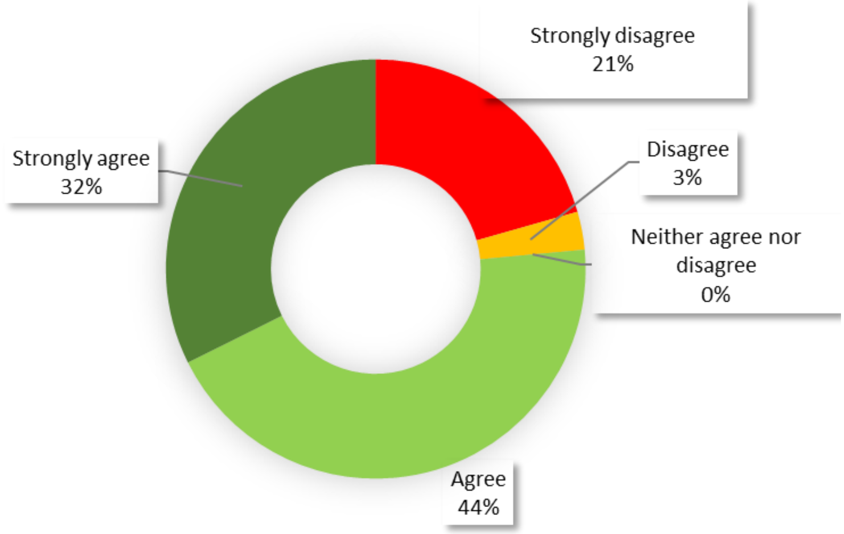

Figure 18: The need to incorporate 4IR technologies into engineering technology education assessments

Just as 76% of lecturers agreed with incorporating 4IR technologies into the engineering technology curriculum in the previous question, 76% of lecturers also agreed with the need to incorporate 4IR technologies into engineering technology education assessments (32% strongly agree and 44% agree). The same applies to the 24% of lecturers who do not see the need to incorporate 4IR technologies into engineering technology education assessments.

The overall score of agreement perception of lecturers on the need to incorporate 4IR technologies into engineering technology education assessment was 73 out of 100, indicating the high level of agreement perception among the lecturers on the need for this.

Table 6: Level of improving teaching and learning process in engineering technology education programmes by 4IR technologies

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No idea	Level of improvement
5G	29%	12%	9%	32%	12%	6%	59.4 Moderate
Virtual reality	29%	12%	0%	41%	18%	0%	58.8 Moderate

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No idea	Level of improvement
Machine learning	29%	9%	0%	41%	21%	0%	57.1 Moderate
Robotics	29%	9%	6%	26%	29%	0%	56.5 Moderate
Artificial intelligence	29%	12%	3%	24%	29%	3%	55.9 Moderate
Internet of things	29%	12%	3%	24%	29%	3%	55.9 Moderate
Data analytics	29%	9%	3%	29%	29%	0%	55.9 Moderate
Nano technology	26%	12%	6%	29%	21%	6%	55.3 Moderate
Additive manufacturing/ 3D printers	29%	12%	3%	18%	32%	6%	54.1 Moderate
Big data	29%	9%	3%	24%	26%	9%	52.9 Moderate
Overall level of improvement							56.2 Moderate

The level of improving the teaching and learning process in South African engineering technology education programmes by each 4IR technology was evaluated out of 100. The results clustered in five groups: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

As shown in Table 6, the lectures believe that all 4IR technologies are able to improve the teaching and learning of engineering technology moderately. Accordingly, the overall potential level of improving the teaching and learning process in engineering technology education programmes by 4IR technologies is moderate (56.2). However, it is concerning to note that 29% of lecturers strongly disagree with the 4IR technologies' level of improving both the teaching and learning process in engineering technology education programmes. This could be due to limited exposure to these technologies on their usage or ignorance of how they function to improve teaching and learning.

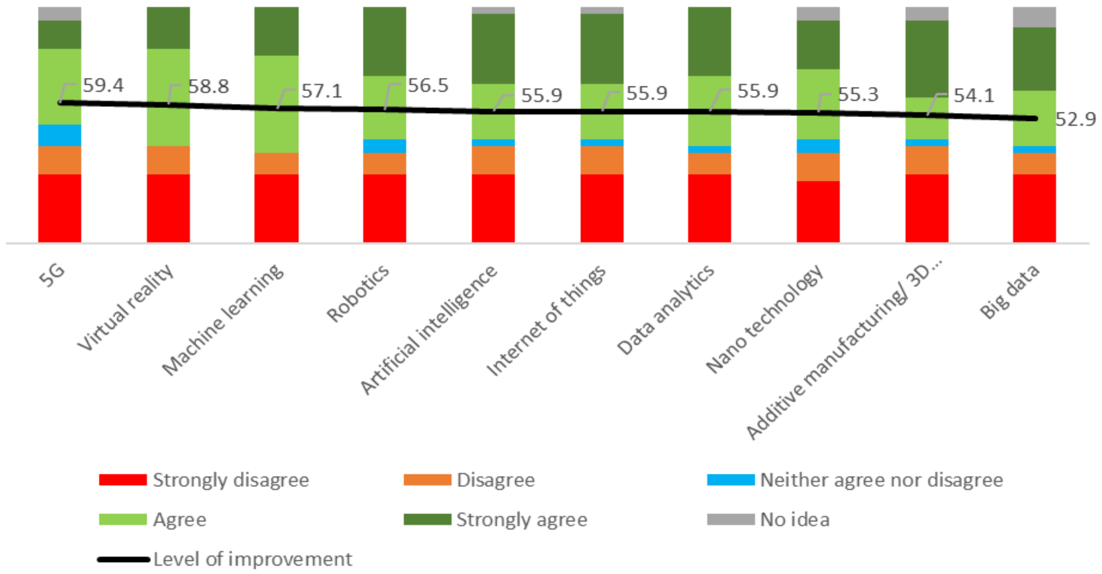

Figure 19: Level of improving teaching and learning process in engineering technology education programmes by 4IR technologies

Table 7: The level of adoption of 4IR technologies in teaching and learning in the engineering technology education programmes

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of adoption
Data Analytics	18%	3%	3%	9%	29%	38%	31.2 Low
Internet of things	9%	0%	9%	21%	15%	47%	25.3 Low
Additive manufacturing/ 3D printers	9%	0%	3%	21%	29%	38%	24.7 Very low
Robotics	3%	0%	18%	12%	24%	44%	22.9 Very low
Nano technology	9%	3%	3%	15%	21%	50%	22.9 Very low

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of adoption
Machine learning	6%	0%	9%	12%	24%	50%	20.6 Very low
Big data	9%	6%	3%	6%	12%	65%	20.0 Very low
Artificial intelligence	6%	0%	6%	12%	24%	53%	18.8 Very low
Virtual reality	6%	3%	6%	6%	15%	65%	17.1 Very low
5G	9%	0%	0%	6%	18%	68%	14.7 Very low
Overall level of adoption of 4IR technology into engineering technology education programme							21.8 Low

According to the data collected from lecturers, the level of adoption of 4IR technology into engineering technology education programmes is low (21.8). The level of adoption of each 4IR technology into South African engineering technology teaching and learning is estimated based on the number of subjects for which lecturers use that specific technology for teaching and learning. Consequently, the level of adoption is classified in five groups: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

As shown in Table 7, the overall level of adoption of 4IR technology into engineering technology education programmes is perceived as low by respondents. Specifically, the level of adoption of data analytics and the IoT into South African engineering technology teaching and learning was believed to be low, while the level of adoption of the other seven 4IR technologies was very low. These low adoption levels could be attributed to a lack of either qualified manpower or resources. The narrative must change if South Africa is to align with the global technological trends in 4IR technological education.

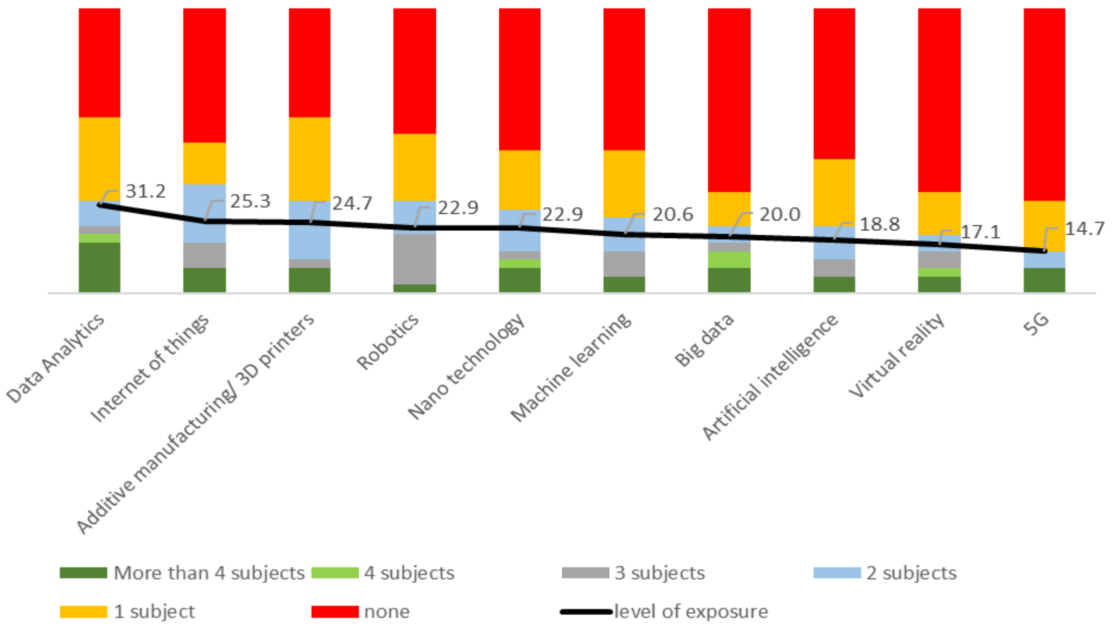

Figure 20: The level of adoption of 4IR technologies into teaching and learning in the engineering technology education programmes

Table 8: Level of adoption of 4IR technologies into laboratory and practical subjects in the engineering technology education programmes

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of adoption
Additive manufacturing/ 3D printers	12%	3%	3%	15%	21%	47%	25.9% Low
Internet of things	12%	3%	6%	12%	18%	50%	25.9% Low
Data Analytics	15%	0%	6%	12%	15%	53%	25.9% Low
Big data	9%	3%	6%	9%	18%	56%	21.8% Very low
Robotics	6%	6%	3%	9%	26%	50%	21.2% Very low
Machine learning	6%	3%	3%	12%	29%	47%	20.6%

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of adoption
							Very low
Artificial intelligence	9%	0%	6%	6%	24%	56%	19.4% Very low
Nano technology	6%	6%	3%	9%	15%	62%	18.8% Very low
Virtual reality	9%	0%	6%	12%	6%	68%	18.2% Very low
5G	9%	3%	0%	9%	6%	74%	15.9% Very low
Overall level of adoption of 4IR technology in laboratory and practical courses							21.6 Low

Similar to the level of adoption of each 4IR technology into South African engineering technology teaching and learning, the levels of adoption of technologies into laboratory and practical subjects were estimated. The results were classified into five groups: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

The level of adoption of additive manufacturing/3D printers, the IoT and data analytics into the laboratory and practical subjects of South African engineering technology is low, while the level of adoption for other 4IR technologies is very low.

In summary, the level of adoption of 4IR technology into engineering technology laboratories and practical courses is also low (21.6), as shown in Figure 20 above. The data indicates that none of the subjects has any significant level of adoption of technology in laboratory and practical aspects of the subjects. This calls for reform if the narrative is to change to align with current universal educational trends

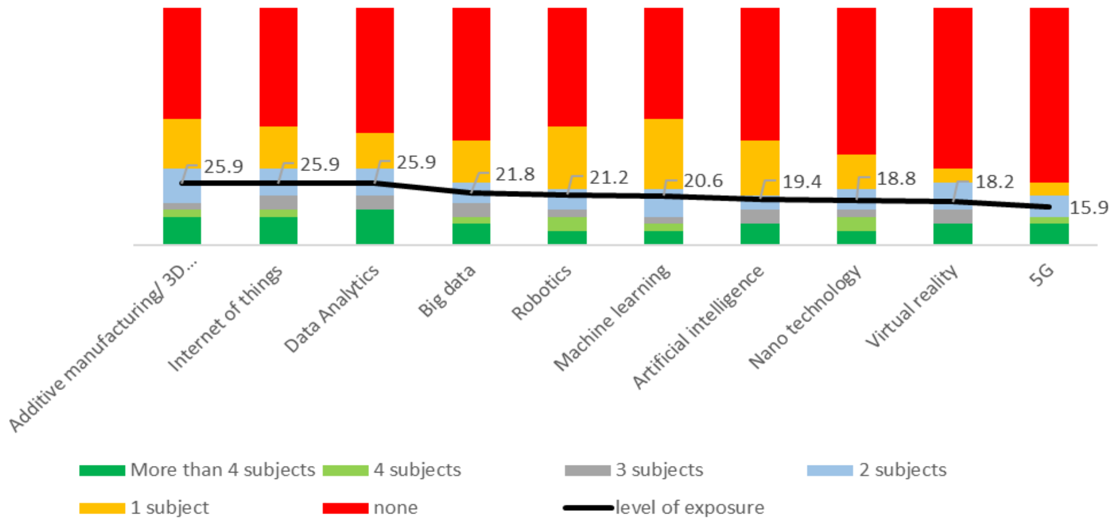

Figure 21: Level of adoption of 4IR technologies into laboratory and practical subjects in the engineering technology education programmes

4.1.3 Student Survey

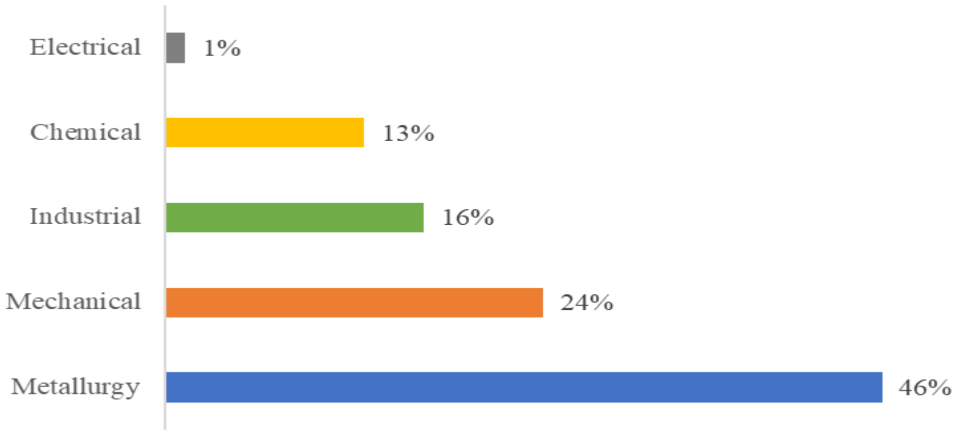

Figure 22: Engineering field of study

As illustrated in Figure 22, the students who participated in the survey study in metallurgy (46%), mechanical (24%), industrial (16%), chemical (13%) and electrical (1%) engineering technology programmes. However, students from other fields of engineering technology such as civil and mining did not participate in the survey.

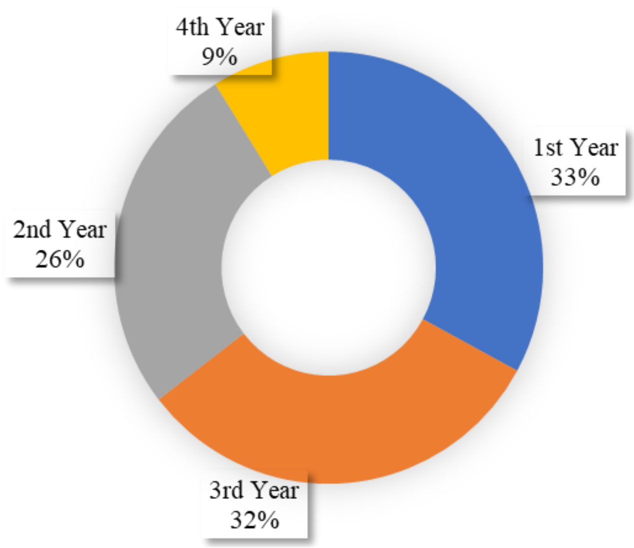

Figure 23: Level of study of students

The students across all levels completed the questionnaire and as shown in Figure 23, 33% of students are in the first year of their programme, 26% in second year with 32% and 9% in third year and fourth year of the programme, respectively. The dominant of the third-year population in this survey is good, as it allows the researcher to gain a better insight into how a more advanced class perceives the concerns the questionnaire tries to address, as they have already accomplished much of the studies in their departments and are therefore better positioned to say what 4IR technology content incorporation is available.

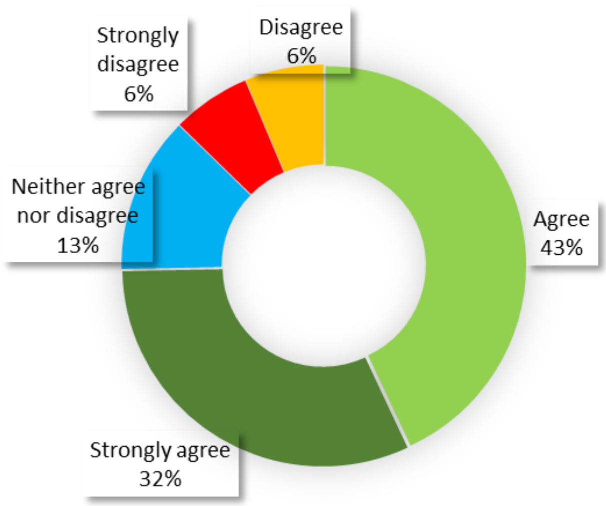

Figure 24: Need to incorporate 4IR technologies into the engineering technology curriculum

As shown in Figure 24, 75% of students either strongly agreed (32%) or agreed (43%) on the need to incorporate 4IR technologies into the engineering technology curriculum. This indicates a yearning for incorporation of these technologies if South African universities are to match up with their international counterparts. On the other hand, only 12% of students disagreed (6%) or strongly disagreed (6%) with integrating 4IR technologies into the engineering technology curriculum; 13% of the students neither agreed nor disagreed.

The 78 out of 100 dominant population agreement proves the high-level agreement perception of students with the need to incorporate 4IR technologies into the engineering technology curriculum. This indicates the awareness levels of students on what 4IR technology can offer in improving teaching and learning

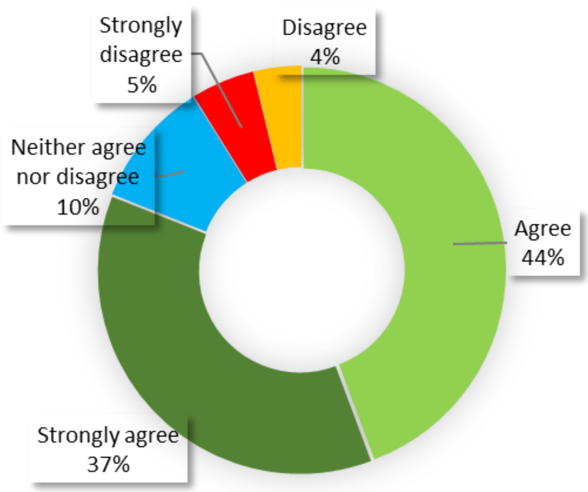

Figure 25: The need to incorporate 4IR technologies into engineering technology education assessments

Similarly, 81% of students agreed with incorporating 4IR technologies into the engineering technology education assessment. Of these, 37% strongly agreed and 44% agreed. On the other hand, only 9% of students did not agree with the need to incorporate 4IR technologies into engineering technology education assessments; 10% are neither agreed nor disagreed.

The overall agreement score of students on the need to incorporate 4IR technologies into the engineering technology education assessment was 81 out of 100, which demonstrates a very high level of agreement among the students.

Table 9: Level of improving learning process in engineering technology education programmes 4IR technologies

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No idea	Level of improvement
Internet of things	5%	0%	4%	43%	46%	3%	83.3 Very high
Virtual reality	3%	0%	6%	46%	42%	4%	82.5 Very high
Additive manufacturing/ 3D printers	1 %	4%	3%	43%	44%	5%	82.0 Very high
Big data	3%	3%	8%	33%	48%	6%	80.5 Very high
Machine learning	3%	8%	4%	39%	42%	5%	79.0 High
Data Analytics	5%	0%	6%	48%	32%	9%	74.9 High
5G	4%	5%	6%	30%	43%	11%	73.9 High
Artificial intelligence	3%	6%	5%	39%	34%	13%	71.6 High
Robotics	6%	11%	8%	33%	30%	11%	67.1 High
Nano technology	3%	8%	6%	39 %	28%	16%	66.6 High
Overall Level of improvement							76.1 High

The level of improving the learning process by each 4IR technology was evaluated based on the students' responses. The results clustered in five groups: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

As shown in Table 9, the students believe the IoT, virtual reality, additive manufacturing/3D printers, and big data are improving their learning very highly, while machine learning, data analytics, 5G, artificial intelligence, robotics and nanotechnology highly improve their learning process. This implies that they are exposed to these 4IR technologies but whether the exposure is within a subject domain is yet to be ascertained.

So, based on the students' responses, the overall learning process in South African engineering technology education programmes can be highly improved through 4IR technology usage.

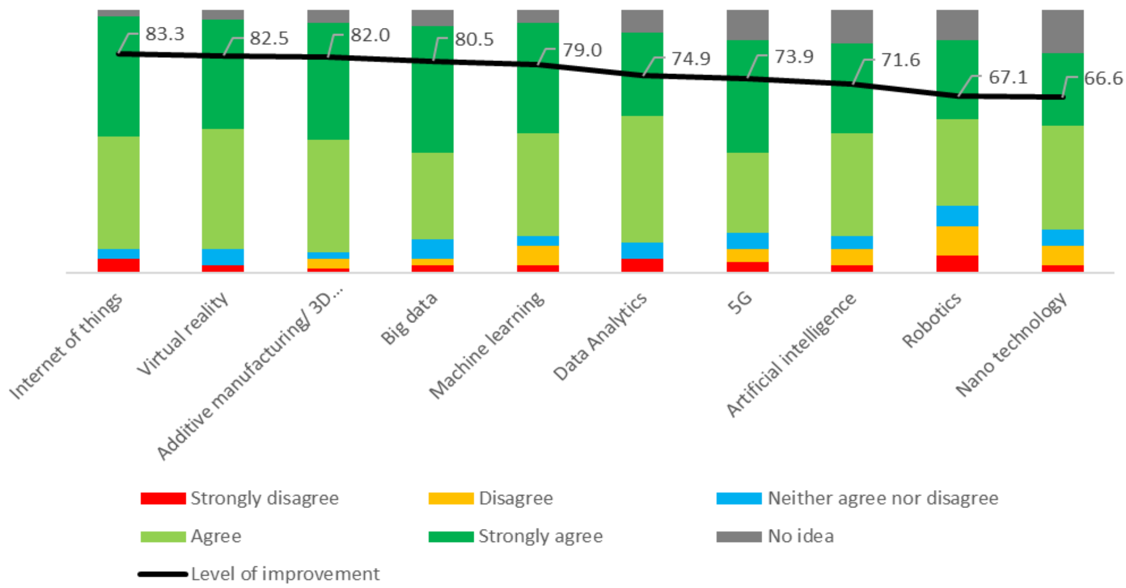

Figure 26: Level of improving learning process in engineering technology education programmes using 4IR technologies

Table 10: The level of exposure of the 4IR technologies among theoretical courses in engineering technology education programmes

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of exposure
Machine learning	22%	15%	15%	16%	16%	15%	52.7 Moderate
Internet of things	32%	5%	9%	11%	8%	35%	47.1 Low

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of exposure
Virtual reality	24%	11%	11%	8%	18%	28%	46.6 Low
Data analytics	19%	10%	8%	11%	18%	34%	39.7 Low
Big data	18%	6%	8%	6%	13%	49%	32.4 Low
Artificial intelligence	8%	14%	4%	10%	9%	56%	26.8 Low
Robotics	8%	4%	6%	10%	15%	57%	21.5 Low
Nano technology	9%	8%	4%	4%	13%	63%	21.3 Low
5G	11%	4%	4%	4%	6%	71%	19.5 Very low
Additive manufacturing/ 3D printers	3%	4%	4%	14%	28%	48%	19.0 Very low
Overall level of exposure of students to 4IR technologies in theoretical courses							32.7 Low

The level of exposure of each 4IR technology to South African engineering technology students was estimated based on the number of subjects that adopted that specific technology for teaching and learning. Consequently, the level of exposure is grouped into five classes: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

As shown in Table 10, students' exposure to machine learning is moderate, whereas their level of exposure to the IoT, Virtual reality, data analytics, big data, artificial intelligence, robotics and nanotechnology is low. Moreover, students are exposed to 5G and additive manufacturing/3D printers at a very low level.

Hence, based on the students' overall perception, the level of exposure to 4IR technologies in their theoretical courses is low (32.7). Their perceptions conform with the lecturers' report so attention needs to be paid to improving the situation if South Africa is to match up with the global trends for improved teaching and learning that enhances knowledge, skills and productivity.

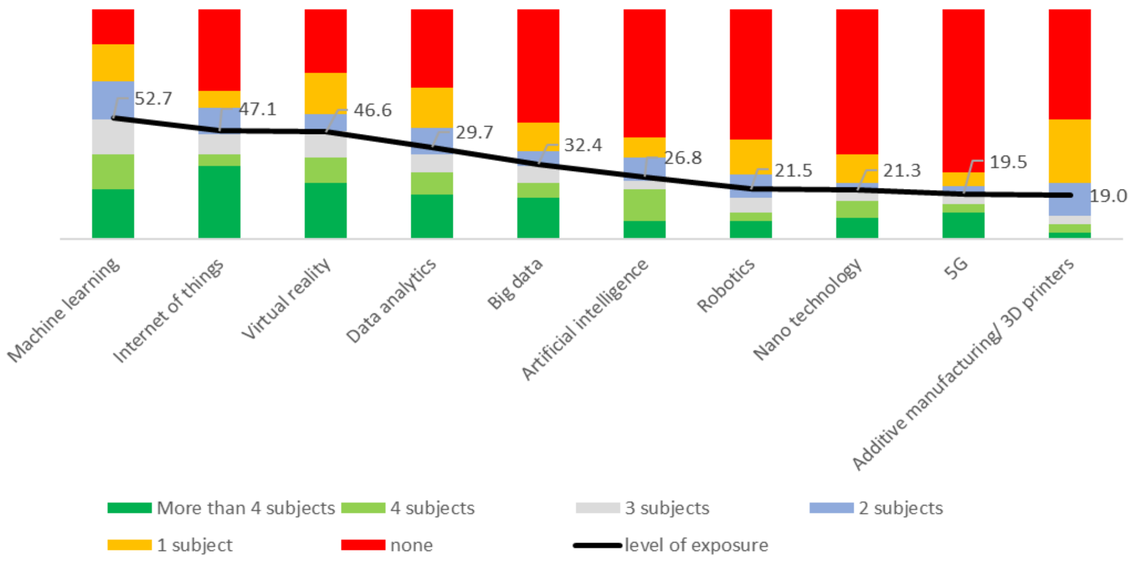

Figure 27: The level of exposure of the 4IR technologies among theoretical courses in engineering technology education programmes

Table 11: Level of exposure of 4IR technologies in laboratory and practical work

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of exposure
Machine learning	22%	15%	10%	20%	16%	16%	51.1 Moderate
Virtual reality	18%	13%	8%	13%	13%	37%	40.0 Low
Robotics	23%	4%	6%	11%	10%	46%	36.2 Low
Additive manufacturing/ 3D printers	15%	9%	9%	11%	15%	41%	35.2 Low

	More than 4 subjects	4 subjects	3 subjects	2 subjects	1 subject	None	Level of exposure
Artificial intelligence	20%	8%	0%	11%	9%	52%	32.7 Low
Nano technology	14%	9%	5%	9%	10%	53%	29.6 Low
Internet of things	5%	3%	6%	11%	28%	47%	21.0 Very low
5G	3%	5%	6%	10%	13%	63%	17.0 Very low
Big data	4%	6%	4%	9%	11%	66%	17.0 Very low
Data Analytics	8%	4%	4%	6%	5%	73%	16.5 Very low
Overall level of exposure of students to 4IR technologies in laboratories and practical courses							29.6 Low

Similar to the level of exposure of 4IR technology in learning, the level of exposure of students to technologies in their laboratory and practical subjects was estimated and the results classified in five groups: very high (81–100), high (61–80), moderate (41–60), low (21–40) and very low (0–20).

The data again shows that students are moderately exposed to machine learning only in their laboratory and practical subjects. The level of exposure of students to virtual reality, robotics, additive manufacturing/3D printers, artificial intelligence and nanotechnology is low and the level of exposure of the IoT, 5G, big data and data analytics is very low in laboratory and practical subjects.

Therefore, based on the students' responses, the overall level of exposure of students to 4IR technologies in their practical courses is low (29.6). This conforms with the lecturers' report so educational reform that includes 4IR technologies is vital if South Africa is to compete favourably with global academia in teaching and learning pedagogy.

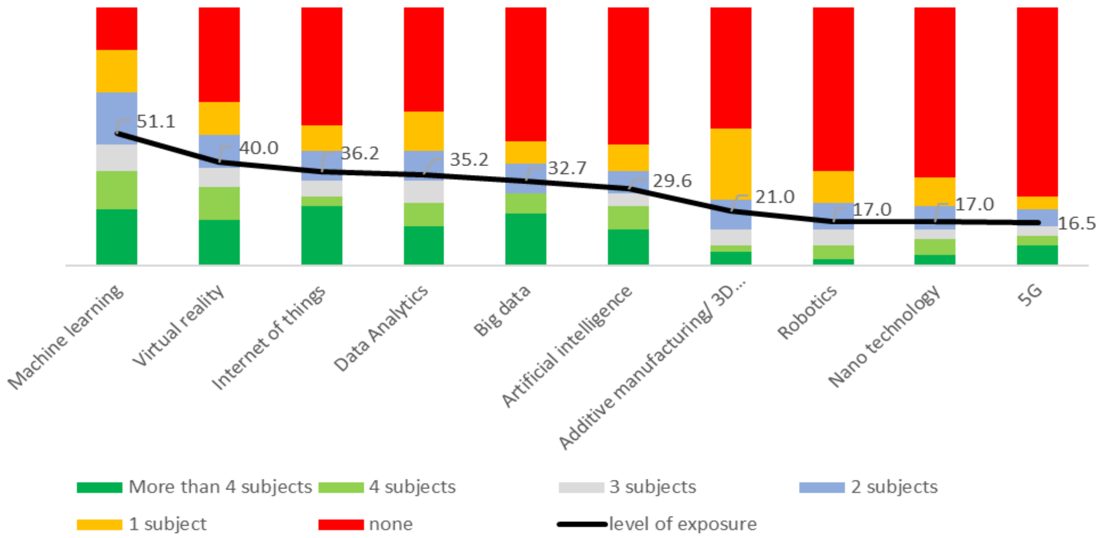

Figure 28: Level of exposure of 4IR technologies in the laboratory and practical subjects

4.2 Cross analysis

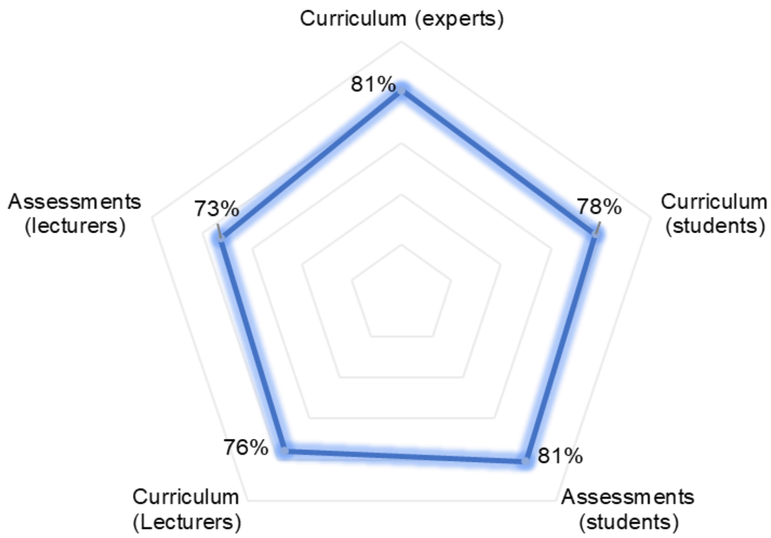

Figure 29: Level of agreement by incorporating 4IR technologies into engineering technology curriculum and assessments

As shown in Figure 29, all three groups of participants highly agreed with the need to incorporate 4IR technologies into engineering technology teaching and learning. The level of agreement between experts and students is very close and higher than the lecturers.

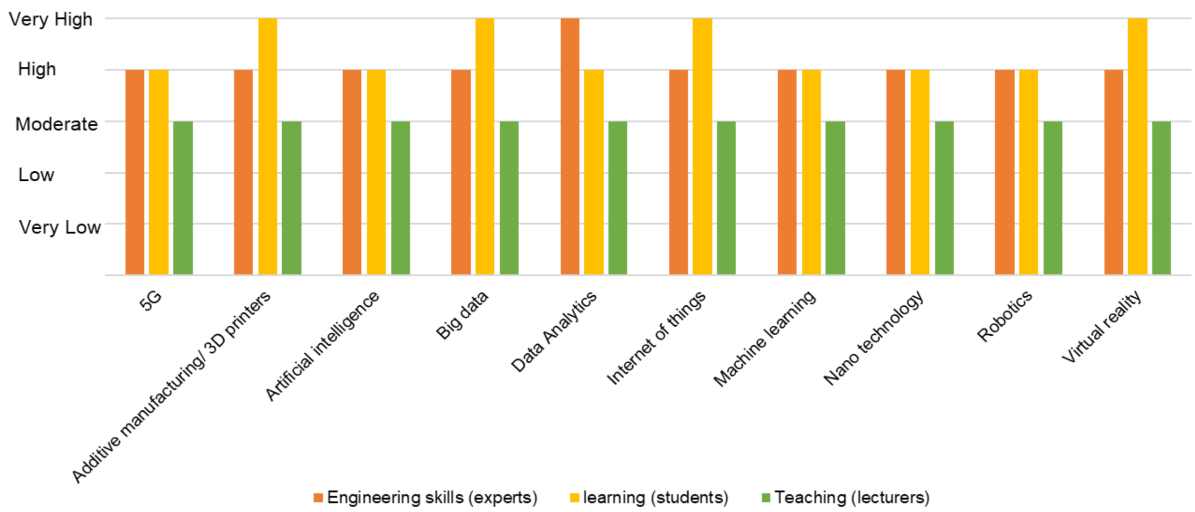

Figure 30: Level of impact of 4IR technologies on engineering skills, teaching and learning

The experts and students inidcated the high to very high impact of technology on engineering skills and learning respectively. Experts only considered data analytics to have a very high impact on engineering skills, while students indicated the high impact of additive manufacturing/3D printing, big data, the IoT and virtual reality on their learning.

On the other hand, lecturers believed all 4IR technologies have moderate impact on the teaching of engineering technology.

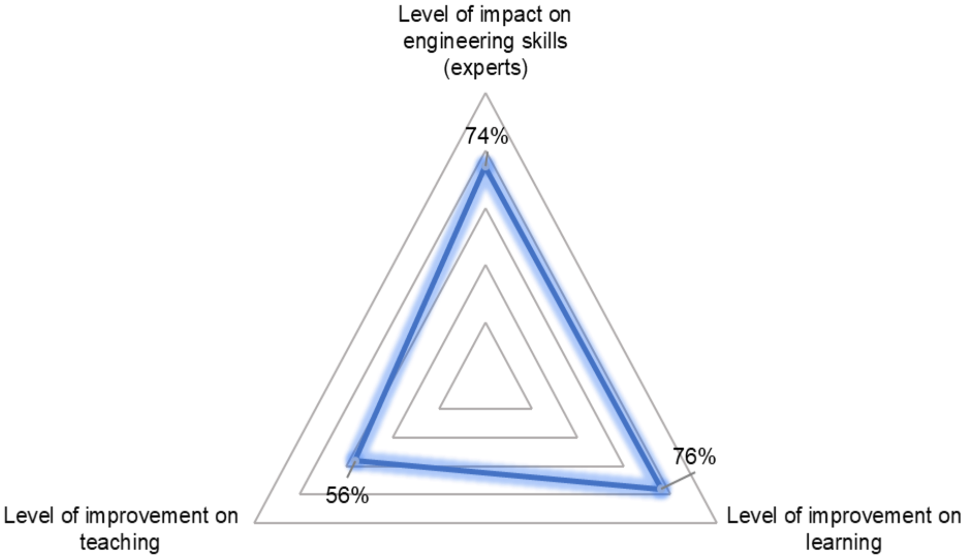

Figure 31: Overall level of impact of 4IR technology on engineering skills, teaching and learning

Similar to the level of the agreement above, the experts' and students' opinions are close to each other regarding the overall impact of 4IR technology, but lecturers evaluate the 4IR technology impact much lower than the experts and students.

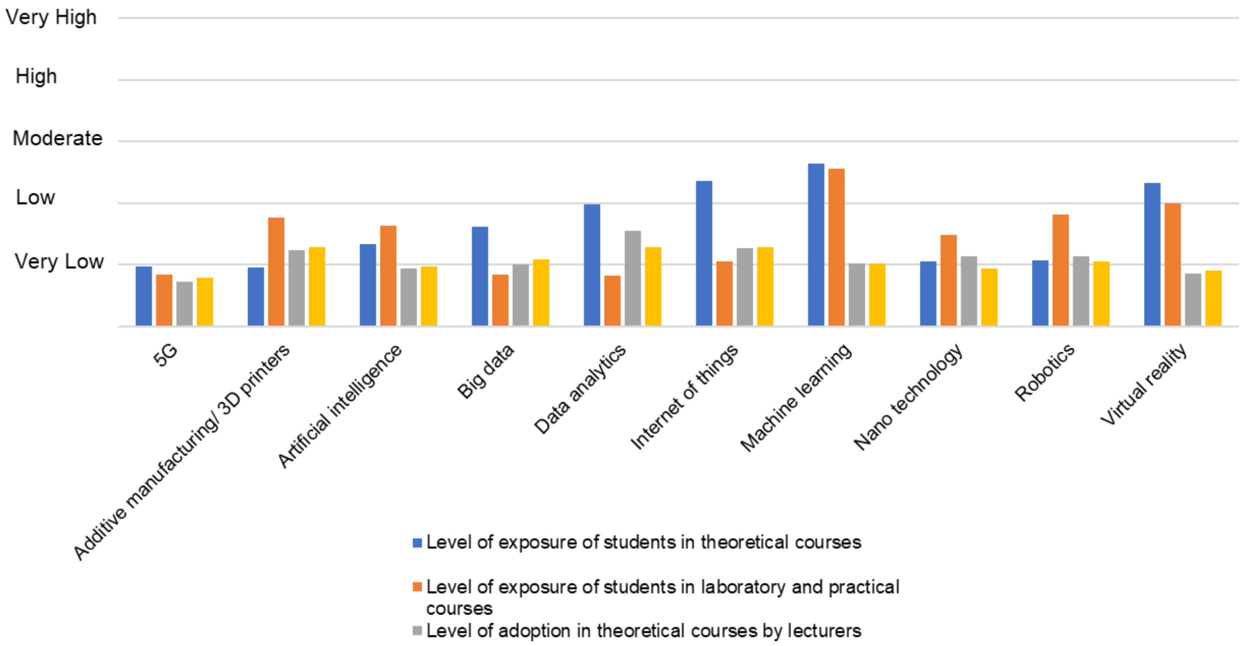

Figure 32: Level of exposure/adoption of 4IR technologies into engineering courses

As shown in Figure 32, the level of exposure of students as well as the adoption of 4IR technologies is very low and low in both theoretical and practical courses.

These very low and low levels of exposures are not aligned with the very high and high potential impact of 4IR technologies on skills, teaching and learning.

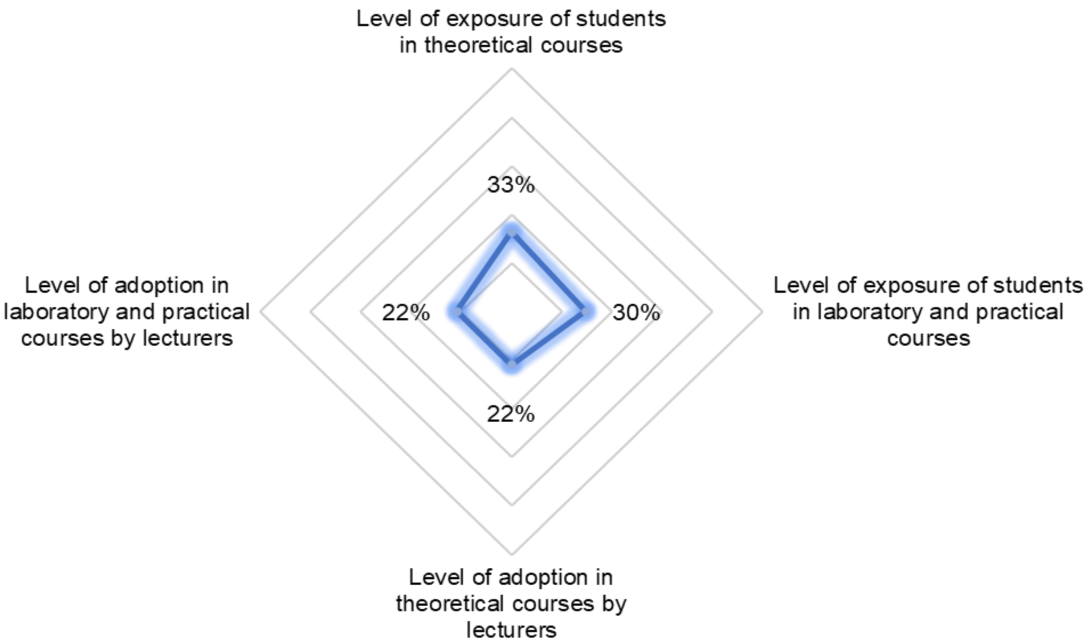

Figure 33: Overall level of exposure/adoption of 4IR technologies in engineering courses

The higher level of exposure of students to 4IR technology compared to the level of adoption of 4IR technology by lecturers can be due to better grasp and interest of students on innovative technologies, which aligns with the higher concern of the impact of these technologies on their learning.

4.3 Qualitative data analysis

Three open-ended questions were designed to obtain unconfined opinions of the three groups of participants (students, lecturers and engineering professionals). These questions aimed to scrutinise the participants' views on the impact of 4IR on the engineering industry, engineering technologists' and technicians' skills and competencies and engineering technology education.

The results of data analysis of these three open-ended questions using content analysis are illustrated in Figure 34 to Figure 36.

"Greater operational efficiency"

"Economic growth"

"Improve efficiency and productivity"

"Improved reliability"

"Supply chain disruption"

"Faster methods of identifying problems and finding solutions"

"Creating safer workspaces"

"Decision-making based on high volume historic data."

"Enhance Predictive analysis"

"Significant savings on resources"

"Reduce the product cost"

"Improved monitoring and process control capabilities"

"Improved communication, efficiencies and reliabilities of systems and processors."

"Mass production"

Figure 34: Impacts of 4IR on engineering industries

As shown in Figure 34, 4IR technologies significantly impact the engineering industries through greater operational efficiency, economic growth, improved productivity, enhanced workplace safety, and predictive analysis.

Moreover, 4IR provides data-oriented, decision-making tools to improve the efficiency and productivity of the engineering industry.

"Requires highly skilled and qualified personnel to operate utility plant"

"Revolutionised the skills and competencies required to remain relevant and competitive in the market"

"Creativity, People management, Emotional intelligence"

"Enhances the analytical thinking and problem-solving skills"

"Enable skills and competencies using virtual platforms that are not limited to equipment availability. Competencies can be simulated in all environments."

"Improved data-driven decision-making"

"upskilling of all skills and competencies"

"Improve professionalism and reliability"

Figure 35: Impacts of 4IR on engineering technology skills and competencies

The analysis results show that even 4IR technologies requiring higher skill in computer literacy can be used as strong tools to enhance the engineering skills of technologists and technicians, such as enhancing analytical thinking and problem-solving.

"Students are able to experience and interact with industrial processes without leaving their classes"

"Teaching, research and service in a different manner, such as MOOCs, virtual classrooms and laboratories, virtual libraries and virtual teachers"

"Deliver adaptive content suitable to all learning styles"

"Enhance delivery of educational material and understanding"

"Ability for students to be assessed out of the norm. Provide an additional and necessary dimension to of assessments. "

"To provide self-adjusting continuous assessment that enables competence-based learning that can be customised for each learner. "

"Independent learning" "Adaptive dynamic learning" "Sharpening self learning"

Figure 36: Impacts of 4IR on teaching and learning in engineering technology education

As illustrated in Figure 36, 4IR technologies are able to impact engineering technology teaching and learning in various ways, such as providing new methods of teaching and learning and customised assessment to students.

5. CONCLUSION

The study used qualitative and quantitative research approaches to explore and examine the perceptions of engineering technology students and lecturers from engineering faculties in the universities of technology and comprehensive universities as well as practising engineering professionals on the impact of 4IR on engineering technology education in South Africa. The study offers the critical role players in technologists' education the opportunity to provide important input that will ultimately shape the engineering technologist curricula.

The findings of the study show that while the 4IR technologies have a high impact on both achieving the required skills and competencies for technologists' and technicians' roles and engineering technology education, unfortunately, there is a low adoption rate of 4IR technologies such as data science, machine learning, IoT, 3D printing, robotics, quantum computing, nanotechnology, etc. Moreover, the study shows that while the incorporation of 4IR technologies in engineering education appears to be broadly supported by engineering students and experts, careful considerations should be taken to bring along the lecturers on board.

6. RECOMMENDATIONS

Based on the findings of this study on the impact of 4IR on Engineering Technology and Technical Education in South Africa, the following recommendations are made for the consideration of the following stakeholders so that South Africa can align with the global technological trends in 4IR technological education.

6.1 ECSA

- ECSA should consider incorporating 4IR-related technologies-based course contents such as data analytics, big data, artificial intelligence, robotics, nanotechnology, 5G technologies, and additive manufacturing/3D printers, etc into the ECSA Policy on Accreditation of Engineering Technology and Technician Programmes (E-01-POL) and Criteria for Accreditation of Engineering Technology and Technician Programmes (E-03-CRI-P).
- ECSA's policymakers who work on various criteria such as Assessment of Graduate Attributes should consider taking the above recommendation further.
- ECSA should consider incorporating the 4IR-related technology-based mode of teaching and learning in Engineering Technology and Technician Programmes into the ECSA Policy on Accreditation of Engineering Technology and Technician Programmes (E-01-POL) and Criteria for Accreditation of Engineering Technology and Technician Programmes (E-03-CRI-P).
- ECSA should consider incorporating the 4IR technologies such as additive manufacturing/3D printers, IoT and data analytics in the laboratory and practical subjects of South African Engineering Technology and Technician Programmes into the ECSA Policy on Accreditation of Engineering Technology and Technician Programmes (E-01-POL) and Criteria for Accreditation of Engineering Technology and Technician Programmes (E-03-CRI-P).
- Since most of the lecturers are unfamiliar with 4IR technologies and their impact on engineering and technology education, ECSA should provide a special mechanism to facilitate the registration of engineering educators and academics as professional engineers and technologies to address the low level of registered South African academics with ECSA.

- ECSA should encourage CPD providers, such as Sector Education and Training Authorities, to offer more relevant courses to enhance the 4IR knowledge and skills of professionals.

6.2 Registered professionals

- The Engineering Technologist/Technician professional should consider the increase in adoption of 4IR technologies such as data analytics, the IoT, machine learning, artificial intelligence, big data, robotics and virtual reality in the industrial environment to facilitate more focus on the associated skills development at the universities.
- The registered professionals, where possible and in a position to do, should facilitate the exposure of the engineering technology and technician in trainees during internship/industrial attachments to the 4IR-related applications for enhancement of the related skills.
- Registered professionals should regularly attend the relevant 4IR CPDs to improve their knowledge and skills.

6.3 Universities

- The universities should consider investing in more qualified 4IR-related manpower and resources for engineering technology and technician programmes.
- The universities should provide enough incentive and motivation to current lecturers to register with ECSA.
- The universities should ensure a conducive environment and policy are put in place for the adoption of 4IR-related technologies in teaching and learning and mode of assessment of engineering technology and technician education programmes.
- The universities should integrate 4IR ethics and practice into their teaching and learning.
- One of the reasons why academic advisory committees (AACs) are needed is to determine academic standards and quality control. For the AACs to be effective, higher education institutions should encourage academic departments to appoint advisory committee members who are professionally registered so that they can advance the mission of ECSA through AACs.

7. FUTURE RESEARCH

- Investigate the challenges and barriers to adopting 4IR technologies into engineering and engineering technology education.
- Study the reasons for low registration of South African academics with ECSA.

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This definitive version of this research report is available on our website.