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CHAPTER 13:

4IR Technological knowledge and skills required by Technical Engineering lectures for the effective curriculum reconstruction of TVET Engineering Programmes

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Abstract

The Fourth Industrial Revolution (4IR) confirms that emerging and quickly evolving technologies are progressively driving the transformation and advancement of all industries and society. It is critical for technical engineering lecturers to keep up with the latest trends and technological advancements within their fields of specialisation, in order to effectively contribute to the development of a technologically literate society, and to share in the advancements brought about by advancing technologies of the early twenty-first century. The TPACK model of Koehler and Mishra is used to examine technical engineering lecturers' pedagogical practices as a complex interplay of their technological knowledge, technological content knowledge, and technological pedagogical knowledge. This chapter examines the empirical findings of a national survey that collected data from N=577 technical engineering lecturers on n=52 campuses of n=24 South African TVET Colleges that offer TVET Engineering study programmes. The purpose of the survey *was to profile TVET Engineering Study lecturers' knowledge and pedagogical practices within engineering programmes across the Republic. A sub-section of the survey specifically probed into participants' awareness and understanding of discipline-specific technological advancements and digital educational enterprises, as well as the potential impact of these on technical teaching. Empirical findings show that 52.3% (n=302) of the participating technical engineering lecturers are unaware of any technological advancements within their area of specialisation, and that they do not know what the potential impact of technological advancements might be on future technical training, following the current reconstruction of the curriculum. This chapter examines the possible implications of these findings for technical engineering curriculum renewal, considering that these lecturers, who are also the key role-players in the current curriculum implementation and evaluation stages, demonstrate limited awareness of technological advancements needed to effectively partake in the 4IR era. The underlying tension between these systems is revealed when Engeström's Cultural Historical Activity Theory (CHAT model) is applied to the activity systems involved. Accordingly, recommendations are made for the professional development of well-trained technical engineering lecturers, harnessed with cutting-edge 4IR technological knowledge and skills required for the current reconstruction of the TVET Technical Engineering curriculum.*

Keywords: TVET lecturers; engineering disciplines; emerging technologies; curriculum reconstruction; technology-integrated learning environments; TPACK model; CHAT model.

Introduction and background

> *"The world is on the brink of a technological revolution that would fundamentally alter the way we live, work and relate to one another. In its scale, scope and complexity, transformation would be unlike anything humankind has experienced before" (Schwab, 2016, Online).*

Technology development and industrial growth are increasing at an exponential rate with expanding global applications driven by the rapid development of emerging and enabling technologies (Brophy et al., 2008; Erboz, 2017; Marr, 2020; Graube & Mammes, 2018). The Fourth Industrial Revolution (4IR) refers to the ongoing automation of traditional manufacturing, production, and industrial practices, through the digitalisation, interconnectivity and communication of systems, using the Internet and other emerging Smart technologies (Erboz, 2017;

Graube & Mammes, 2018; Nundkumar & Subban, 2018; Philbeck & Davis, 2019). In Germany, the term Industry 4.0 is used synonymously when referring to the 4IR, the USA prefers Industrial Internet Consortium, while in Japan and Asia it is called the Industrial Value-Chain Initiative (IV-I). However, according to Philbeck and Davis (2019, p. 17), Industry 4.0 refers to a specific component within the larger concept of the 4IR, which specifically focusses on the relationship between digitization, organizational transformation, and productivity enhancement in manufacturing and production systems. The 4IR “affirms that technological change is a driver of transformation relevant to all industries and parts of society” (Philbeck & Davis, 2019, p. 17). The emerging transformation of cyber-physical systems that were brought about by disruptive emerging digital technologies, through the Internet of Things, the Internet of Services, and the Internet of Industrial Things, gave rise to the 4IR (Schwab, 2016; Winston et al., 2017). “Large-scale integration of machine-to-machine communication (M2M), Smart technologies, and the Internet of Things, drastically increased the automation of industries through improved communication and self-monitoring, and Smart machines that can analyse and diagnose issues without the need for human intervention” (Moore, 2019, Online). The 4IR is increasingly connecting a diverse range of emerging technologies in order to create value, not only for industries, but for all aspects of human life.

Table 1: Examples of emerging 4IR Technologies

Fourth Industrial Revolution (4IR) Technologies	
▪ 3D-Printing & 4D-Printing ▪ Advanced Materials & Intelligent Materials ▪ Agile Robots ▪ AI discovered chemical compounds, e.g. Covid-19 vaccines ▪ Androids ▪ Anti-aging drugs, e.g. senolytics ▪ Anti-lasers ▪ Artificial Intelligence & AI of Things ▪ Augmented Reality ▪ Automated food inventories and shopping ▪ Automated pilot avionics ▪ Automation ▪ Autonomous Vehicles ▪ Big Data ▪ Bionics ▪ Biorobotics ▪ Biotechnology, Genomics & Genetic Engineering ▪ Blockchains ▪ Cloud Technology ▪ Cloaking Devices ▪ Collaborative Robots (Cobots) ▪ Cybernetic organisms (Cyborgs) ▪ Cyber-Physical Systems (CPS) ▪ Distributed robotics ▪ Drones ▪ Edge Computing ▪ G5 Cellular Network Technology ▪ Global digital currency, e.g. Libra ▪ Hyper-personalised treatment for genetic mutations ▪ Industrial Internet of Things (IIoT)	▪ Intelligent Algorithms ▪ Internet of Autonomous Things (AuT) ▪ Internet of Energy (IoE) ▪ Internet of Military Things (IoMT) ▪ Internet of People (IoP) ▪ Internet of Services (IoS) ▪ Internet of Things (IoT) ▪ Internet of Vehicles (IoV) ▪ Interplanetary Internet ▪ Machine Learning ▪ Magnetic implants ▪ Massive Open Online Courses (MOOCs) ▪ Mobile cyber-physical systems ▪ Nano Materials & Nanotechnology ▪ Optical computers & light computing ▪ Predictive Analytics ▪ Process control systems ▪ Prosthetics ▪ Quantum Computing ▪ Quantum Entanglement &Tunnelling ▪ Satellite mega-constellations ▪ Simulation ▪ Smart baby care sensors ▪ Smart grids ▪ Smart-homes ▪ Supreme quantum computing ▪ Synthetic Biology ▪ Ubiquitous Production & Control ▪ Virtual Reality ▪ Wearable devices (e.g. watches, Smart-shirts)

The rapid rise and convergence of emerging 4IR technologies, of a few examples of which are listed in Table 1, are progressively steering the digital transformation of industries, companies, institutions, governments, economies, societies, and nations at large. The value contribution of the 4IR relies upon electronic identification, where set technologies are required for Smart manufacturing to be incorporated into manufacturing processes, in order to advance beyond mere digitisation (i.e. computerisation and connectivity), and to become part of the development path of Industry 4.0, i.e. visibility, transparency, predictive capacity, and adaptability (Schuh, Anderl, Gausemeier, ten Hompel & Wahlster 2017). Notably, industrial automation cyber-physical systems are radically and exponentially transforming most production and manufacturing industries, where cyber-physical systems are applied, e.g. to conventional programmable logic controllers, for more advanced controlling and monitoring of electromechanical processes (Thramboulidis, 2015).

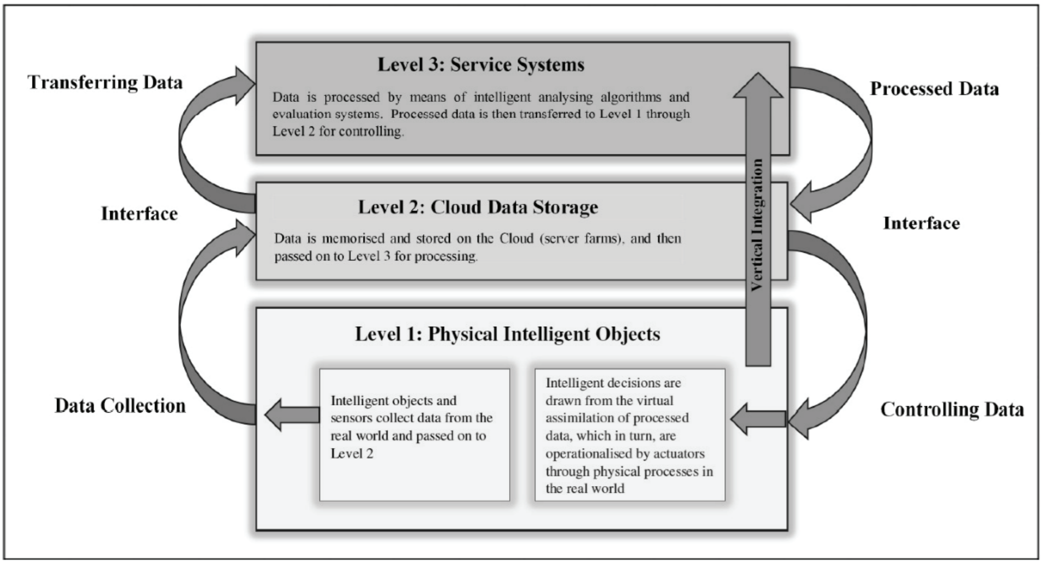

Figure 1. Design of a basic Cyber-Physical System (CPS) used in Smart production and manufacturing industries for automated control and monitoring of processes, adapted from Draht (2014, p. 51)

In the first integration level of a basic cyber-physical system (Figure 1), various forms of intelligent objects, Smart devices, and sensors, collect data and monitor physical processes, in order to design and create a virtual copy of the real world. On the second cyber level (Figure 1), data is memorised, identified according to variation, clustered for similarity, and stored in the Cloud, and then transferred to Level 3, where intelligent analysis algorithms and evaluation systems process the data. Processed data is transferred back to Level 1 through Level 2 that is controlling the data. Intelligent decisions, i.e. self-configured, self-adjusted, and self-optimised, are drawn from the virtual assimilation of processed data, which in turn, are operationalised by actuators through physical processes in the real world (Draht, 2014). “Physical and software components are deeply intertwined in cyber-physical systems, and are able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioural modalities, and interact with each other in ways that change with context” (US National Science Foundation, 2021, Online).

	Levels of Autonomy	Transition Stages from Industrial Automation to Industrial Autonomy	Attributes
Industrial Autonomy	6	Symbiotic Autonomy	Autonomous operations of multi-collaborating ecosystems of companies are brought together via the Industrial Internet of Things and optimised across the industry, in order to achieve full autonomous interaction of data, resources and processes across separate industrial/manufacturing plants, without any human control or interference
	5	Autonomous Operations	Industrial/manufacturing facility is completely autonomous, including process operations, control, supply chains, etc.
	4	Autonomous Orchestration	Industrial/manufactioring facility operates autonomously, synchronised to optimise manufactioring, productovity and safety under most circumstances
	3	Semi-Autonomous	A mixture of autonomous and automated assets with human orchestration
Industrial Automation	2	Automated	Humans responsible for safe operations, assisted by traditional aitomation systems
	1	Semi-Automated	Humans and automation systems, e.g. cyber-physical systems, share the workload, but humans responsible for safe operations.
	0	Manual	All industrial and manufacturing facilities and processes are manually controlled by humans

Figure 2. Transition stages of industries from Industrial Automation to Industrial Autonomy (adapted from Yokogawa (2021, Online))

Industrial and manufacturing processes are being automated aggressively, due to the growing capabilities of cyber-physical systems which progressively monitor, control, and make independent decentralised decisions (Erboz, 2017). The global enforcement of social distancing regulations, in response to the tenacity of the ongoing Covid-19 pandemic, further accelerates the automation of industries (Marr, 2020). Figure 2 summarises the various levels of industrial automation, from the lowest level of autonomy, in which all industrial and manufacturing processes are still manually controlled by humans, to the highest level of symbiotic autonomy, in which autonomous operations of multi-collaborating ecosystems, are brought together via the Industrial Internet of Things. These are then optimised across an industry. in order to achieve full autonomous interaction of data, resources and processes across separate industrial / manufacturing plants, without any human control or interference (Yokogawa, 2021).

The rapid digitisation and automation of industries, however, has also brought new challenges for future labour markets. Automated systems are constantly raising the complexity of tasks, which in turn, incessantly demands higher levels of skills for entry-level positions (Makgato, 2019). Another concern, raised by Shusterman (2015), is that many education and training institutions are currently educating and preparing students for obsolete occupations and work for which human activities are no longer required, due to the continuous digital automation and transformation of industries. Makgato (2019, p. 390) voiced the same concern:

> *"Youth and people who lack high level technological and interpersonal skills are becoming vulnerable due to digital automated jobs. There is a need for targeted and strategic skills, education and training that are responding to the changing technological world… …supporting the application of transferable skills will be a key priority as we foster a sustainable and more productive economy".*

A technology and knowledge driven economy requires a well-trained workforce coupled with cutting-edge industry-based knowledge and skills in science, technology, engineering, and mathematics, to sustain the growing and ever-changing demands brought forth by the digital transformation of production and manufacturing industries. In his 2019 State of the Nation Address, President Cyril Ramaphosa remarked:

> *"The world we now inhabit is changing at a pace and in a manner that is unprecedented in human history. Revolutionary advances in technology are reshaping the way people work and live. They are transforming the way people relate to each other, the way societies function and the way they are governed… we are faced with a stark choice. It is a choice between being overtaken by technological change or harnessing it to serve our developmental aspirations. It is a choice between entrenching inequality or creating shared prosperity through innovation… To ensure that we effectively and with greater urgency harness technological change in pursuit of inclusive growth and social development, I have appointed a Presidential Commission on the 4th Industrial Revolution…[that] ... serves as a national overarching advisory mechanism on digital transformation" (Republic of South Africa, 2019, Online).*

TVET Colleges, as "significant and necessary participants" in the 4IR (Nundkumar & Subban, 2018, p. 309), aspired to fulfil these demands. In his 2017 budget addressed to Parliament, the Minister of Higher Education, Science and Innovation, Dr. Blade Nzimande (2017), acknowledged 4IR as an opportunity to speed up economic development and advance skills for industrialisation, and mandated TVET Colleges to yield individuals who can embrace change brought about by technology.

In his 11th of February 2021 parliamentary reply to a question raised during the National Assembly, Minister Nzimande (2021, Online) reported that:

> *"Since 2018, the Department has embarked on a plan to review and update programmes and qualifications offered at Technical and Vocational Education and Training (TVET) colleges in order to align them with the needs of industry and society. This plan has focused on the following aspects of the curriculum:*
>
> 1. *Integrating digital skills knowledge into current programmes*
> 2. *Introducing new programmes in response to the fourth industrial revolution (4IR)*
> 3. *Phasing out of outdated programmes*
> 4. *Reconstruction of Engineering programmes to make them more responsive to the changing industry environment; and*
> 5. *Revision and updating of subject content".*

The Department of Higher Education, Science and Innovation, supported by CISCO Systems, Inc., an American multinational technology conglomerate, "developed digital skills training, which has been integrated into the National Certificate (Vocational) [NCV] programme. Knowledge of the use of the internet, email, cyber security and databases are examples of digital skills training that have been integrated into the NCV programme" (Nzimande, 2021, Online). The Department has also "developed a new stream focusing on Robotics in the NCV: Information Technology and Computer Science programme, which previously focused on programming and systems development only. This stream will cover subjects such as Electronic and Digital concepts for Robotics, Robotics Fundamentals, and Industrial Automation. The curriculum for this programme is currently being quality assured by UMALUSI and is envisaged for implementation in 2022" (Nzimande, 2021, Online).

According to Minister Nzimande (2021, Online), "the Department has collaborated with the Quality Council for Trades and Occupations (QCTO) in reconstructing curricula of Engineering Studies programmes to align with industry needs and standards of professional bodies. The programmes that have been prioritised and are currently being reconstructed are in the following fields: Electrical Engineering, Electronics Engineering, Mechanical Engineering and Civil Engineering. Curriculum reconstruction of engineering programmes commenced in August 2020 and is anticipated to be completed by June 2021. The completion of this process will see a reduction in the offering of the current NATED programmes and a move to occupational programmes, which are more industry-aligned". Since 2018, the curricula of 38 subjects in the NATED programmes were updated, covering Engineering, Business and Services studies. The implementation of these revised/updated curricula started in January 2021 (Nzimande, 2021).

At the 2020 launch of the Engineering Programme at the University of Zululand, Minister Nzimande (2020, Online), appealed to the management of HEIs "not to compromise standards in offering… engineering programmes", and furthermore expressed his "trust that those who are appointed to teach in these qualifications also hold the best qualifications in the engineering disciplines and command the best experience from related industries". He also called upon "industries… to rally resources together… [to] invest in the development of engineering infrastructure at…. [HEIs] … and provide good experiential learning opportunities for students who will be pursuing their engineering qualifications" (Nzimande, 2020, Online). In order for Technical Engineering lecturers to be able to "command the best experiences from related industries" and to "provide experiential learning opportunities for students", they need to keep abreast with the latest trends and technological advancements within their fields of specialisation, and the way in which emerging technologies are exponentially changing and transforming both industries and the training of Technical Engineering students.

It has become imperative for Technical Engineering lectures to stay abreast of the latest emerging technologies in their areas of specialisation, and to take up the challenge to continuously upskill themselves in the integration and pedagogical use of these emerging technologies, in order to enable the effective preparation of TVET students for advancing technological driven Industries. Technical Engineering lecturers are mandated to be experts within their fields of specialisation, and to effectively mediate the professional development of their novice students. This is should be done in order to gain not only theoretical knowledge, but also applicable digital skills and hands-on technological capabilities that industries will require from them. Even so, almost nothing is known about Technical Engineering TVET lecturers' awareness of industry-relevant technological advancements in their areas of specialisation, nor about their knowledge and practical skills in the pedagogical use or/and application of said technologies. It is also unclear whether or not Technical Engineering lecturers are actually considering the transformative impact that emerging technologies will have on their future teaching practices. Accordingly, this paper reports the empirical findings of a sub-section of a National survey study, that are informative in finding answers to these unresolved questions.

In order to create and mediate industry-relevant learning opportunities for students in technology-integrated learning environments, it has become essential for Technical Engineering lecturers to:

- Effectively attain and mediate the acquisition of 21st Century skills;
- Make the pedagogical shift from a transmission-based approach, to a transformative-based pedagogical approach, in which Technology is interwoven and used as a tool to mediate 21st century transformative learning experiences;
- Continuously develop and upskill their technological literacy and digital competencies, in order to stay abreast with the latest industry-based technological advancements in their fields of specialisation;
- Acquire and implement various types of technological knowledge into their pedagogical practices;

- Progressively integrate industry-relevant technologies and digital competencies into their pedagogical practices to achieve 21st century learning outcomes;
- Mediate the development of higher-order thinking skills and digital savvy among their Engineering students; and
- Self-evaluate the objectives, activities, and processes of their pedagogical practises.

Drawing from the available corpus of knowledge, these essential requirements are explored in the next section, as they constitute the theoretical underpinnings of the research component (i.e. a sub-section of a larger National survey study), of which the findings are reported in this chapter.

Theoretical underpinnings

Acquisition of 21st Century skill

21st Century skills are the abilities required in order to be effective workers, citizens and leaders in the global economy (Madhav et al., 2018).

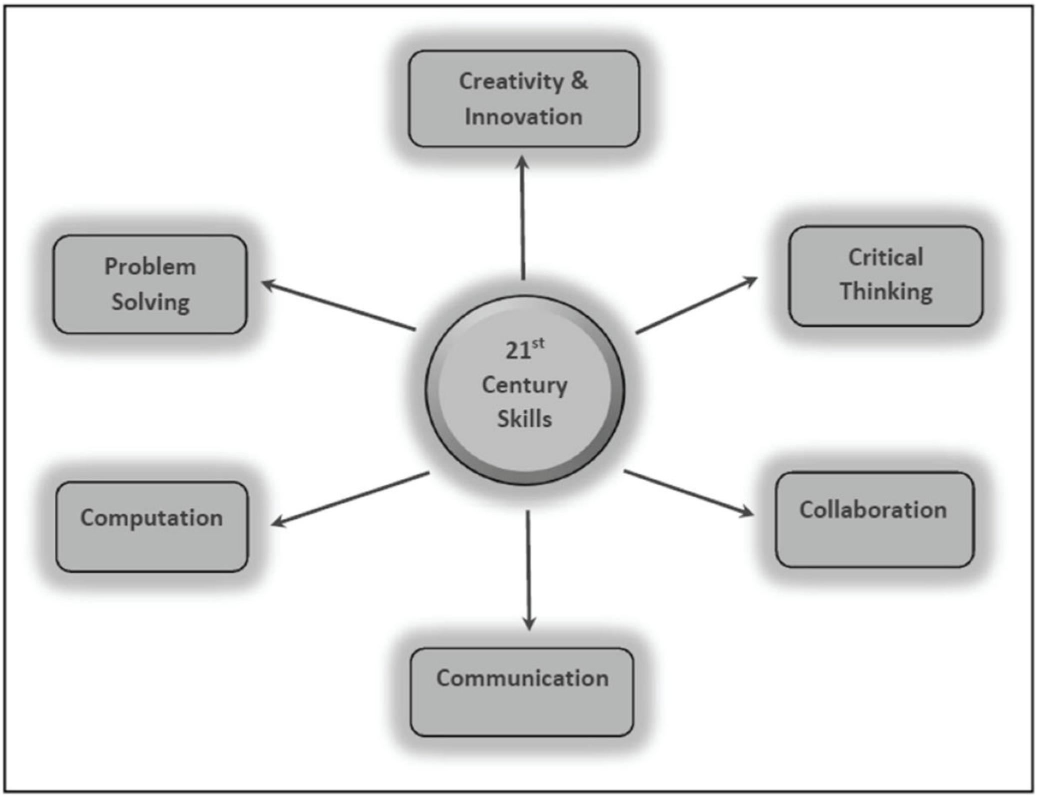

Figure 3: Essential 21st Century Skills, adapted from Madhav, Simelane-Mnisi, Hardman, Dlamini and Lilley (2018, p. 115)

Figure 3 shows essential 21st Century skills in which Technical Engineering lecturers should become experts, in order to effectively mediate the development and acquisition of these skills among their students. In order to develop communication skills amongst their students, Technical Engineering lecturers could, for example, ask students to share with the class how they solve problems. When students give correct answers, they should also be asked to explain how they arrived at their answers. Creativity requires the generation of new ideas and novel solutions to problems. Students could, for example, be provided with open-ended design challenges to get them to develop novel ways to solve established problems. Collaboration should still be encouraged in the information age, as people no longer work individually to solve problems, but rather work together. Collaboration could be cultivated, e.g. by giving students group work problems that require the input and the collaboration of all the students.

Continuous professional development of technological literacy and digital competencies

According to Dakers (2018, p. 23), being technological literate "is something that one never actually becomes. One is, rather, always in the process of becoming, just as technologies are always in the process of becoming". Digital competencies cannot be assessed in terms of right or wrong, as one is always in the process of becoming more technologically literate and more digitally competent. Furthermore, technological skills are not the defining factor for effective digital pedagogy. Effective digital pedagogy is much more about an attitude towards, and an aptitude with digital technologies, than having certain predetermined technological skills. Digital pedagogy requires a willingness to use new technologies effectively in classes, and to understand how and why they should be used (Burtis, 2016; Hardman et al., 2018; Howel, 2012; Stommel, 2013).

Figure 4 illustrates the Technological Pedagogical Content Knowledge (TPACK) model, first proposed by Koehler and Mishra (2006), which also forms part of the Department of Basic Educations' (2018) Professional Development Framework for Digital Learning.

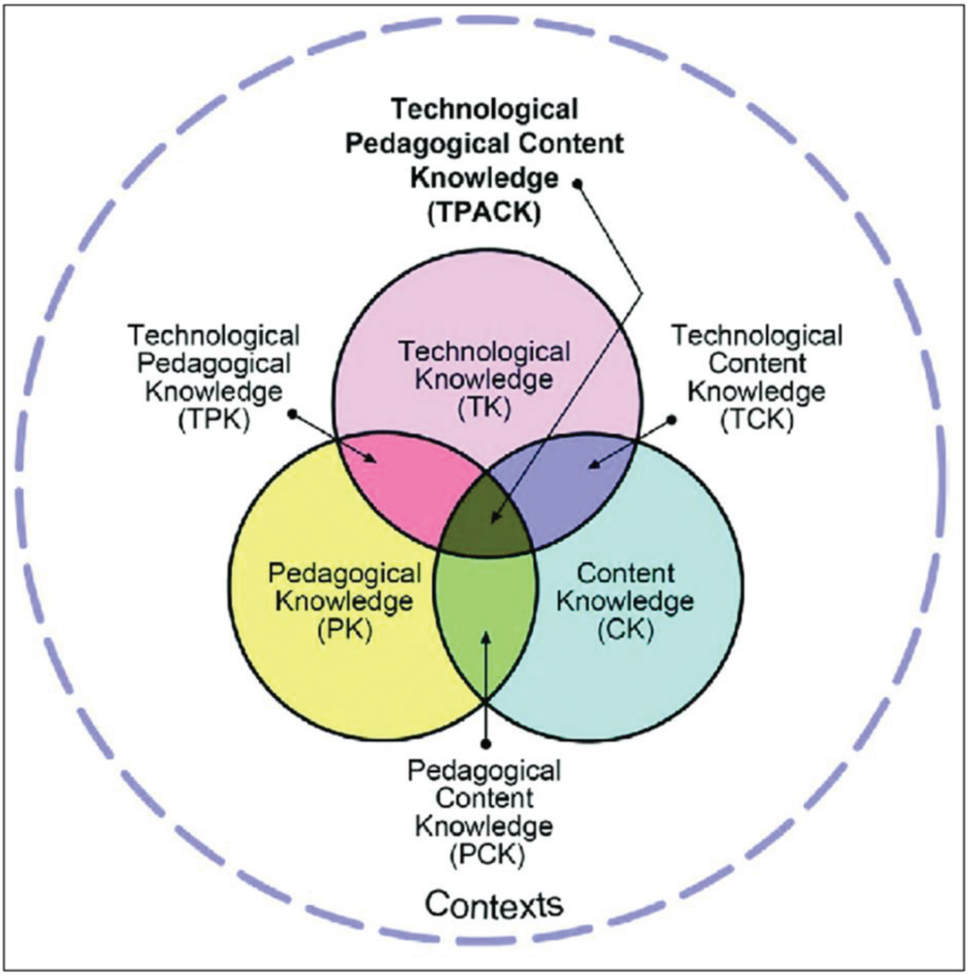

Figure 4: Technological Pedagogical Content Knowledge (TPACK) Model of Koehler and Mishra (2006)

The TPACK model emphasises that 21st Century teaching has become a highly complex activity, which embraces various kinds of knowledge. Cognisance and integration of the various types of TPACK knowledge, will enable Technical Engineering lecturers to use technology in their lessons effectively. The lecturer starts from the point of his/her subject knowledge, and then selects an appropriate technological tool for a lesson on her/his subject. The technology tool informs the selection of relevant pedagogical teaching methods (Hardman et al., 2018). When the TPACK model is applied to the educational context of Technical Engineering TVET lecturers, it illuminates the complex interplay of various types of knowledge that Technical Engineering lecturers need to attain and integrate as part of their 21st century pedagogical practices (Table 2).

Table 2: Various types of technological knowledge applicable to Technical Engineering lecturers

Various Types of Knowledge	Defined for Technical Engineering TVET lecturers
TK **Technological Knowledge**	Technical Engineering lecturers' knowledge about how to use different kinds of ICT hardware and software and associated peripherals, how to operate them, and how to troubleshoot when necessary.
TCK **Technological Content Knowledge**	Pertains to Technical Engineering lecturers' knowledge about the way technology and content are linked, and how lecturers can transform their subject matter through the use of technology.
TPK **Technological Pedagogical* Knowledge**	Entails knowing how the use of ICTs enables teaching, and how Technical Engineering lecturers' approach to teaching can be transformed by ICT tools
PK **Pedagogical* Knowledge**	Technical Engineering lecturers' knowledge about students' learning, instructional methods, different educational theories, and learning assessments to teach subject matter without references towards content.
CK **Content Knowledge**	Technical Engineering lecturers' knowledge of the subject matter, without considering how to teach the subject matter.
PCK **Pedagogical* Content Knowledge**	Technical Engineering lecturers' knowledge of representing content knowledge and adopting pedagogical (andragogical) strategies to make the specific content/topic more understandable for students

**Note*
Although Koehler and Mishra's (2006) Technological Pedagogical Content Knowledge (TPACK) model is assimilated into the Department of Basic Educations' (2018) Professional Development Framework for Digital Learning, it also serve as a tool to illuminate the complex interplay of various types of knowledge that Technical Engineering lecturers need to attain and integrate as part of their 21st century pedagogical practices (Hardman, Molotsi, Lilley, Madhav, Simelane-Mnisi & Dlamini, 2018). Within TVET education, It would be more appropriate to use the term "Andragogical", instead of "Pedagogical", when referring to the education of adult TVET students

Table 3: Linking Technical Engineering lecturers' SAMR levels of technology integration (Puentedura, 2006, 2014) with Bloom's (1956) Revised Digital Taxonomy (Anderson & Krathwohl, 2000), in order to mediate the development of higher order thinking skills among Technical Engineering students' (adapted from Puentedura (2006, 2014))

	Levels of Technology Integration	Pedagogical Use of Technology	Bloom's Revised Digital Taxonomy	Mediation of Engineering Students' Development of Thinking Skills
TRANSFORMATION	Redefinition	The task is altered so fundamentally by the technology that it cannot be done without the technology. The use of technology enables the accomplishment of tasks that were previously inconceivable.	Create	Designing, constructing, planning, producing, manufacturing, inventing, devising, programming, animating, broadcasting, filming, publishing
			Evaluate	Experimenting, hypothesising, testing, monitoring, critically evaluating, reviewing, posting, moderating, virtually collaborating and networking with experts in the field
	Modification	Technology is used to accomplish learning outcomes. The teaching and learning process is transformed by the use of technology. The task alters functionally in the presence of the technology. Technology allows for significant task redesign. Further integration: redesign the task by the use of technology.	Analyse	Comparing, organising, deconstructing, attributing, outlining, finding, structuring, integrating, linking, validating, cracking, reverse engineering
ENHANCEMENT	Augmentation	Appropriate tools are used to enhance teaching and learning. Further integration: learning task is slightly altered to augment work that is usually done in a traditional way. The task is functionally improved by the use of technology.	Apply	Implementing, carrying out, using, executing, loading, playing, operating, hacking, uploading, sharing, editing
	Substitution	Technology is still used in the same way as was done in 20th century. Further integration: replace a traditional tool or technology with an emerging technology in such a way that the learning task is not functionally altered, i.e. the technology acts as a direct substitute for a tool with no functional change.	Understand	Interpreting, summarising, inferring, paraphrasing, classifying, categorising, comparing, explaining, exemplifying, advance searching, Boolean searches, blogging, tagging, commenting, annotating
			Remember	Recognising, listing, describing, identifying, retrieving, naming, locating, finding, bulleting, pointing out, highlighting, bookmarking, social networking, social bookmarking, local bookmarking, Googling

Progressive Levels of Technology Integration

Progressive Development of Lower- to Higher-Order Thinking Skills

Technical Engineering lecturers' pedagogical integration and use of industry-relevant technologies

The levels of technology integration, proposed by Puentedura's (2006, 2014) Substitution-Augmentation-Modification-Redefinition (SAMR) model, offers Technical Engineering lecturers the opportunity to self-evaluate and determine their progressive levels of pedagogical technology integration, i.e. from the lowest Substitution level, to Redefinition as the highest level of technology integration (first two columns of Table 3). The SAMR model could assist Technical Engineering lecturers "to consider how to take full advantage of the benefits of emerging technologies" (Hardman et al., 2018, p. 27). The first two integration levels, i.e. Substitution and Augmentation, denote the enhancement of teaching and learning through the use of technology; while the third and fourth levels of integration, i.e. Modification and Redefinition, epitomise the tangible transformation from traditional to 21st century technology-integrated teaching and learning practices (Puentedura, 2006, 2014). The 2nd column in Table 3 describes the integration criteria for each of the progressive levels of pedagogical technology integration.

Bloom's (1956) Revised Digital Taxonomy (Anderson & Krathwohl, 2000) is incorporated into the 3rd and 4th columns of Table 3, representing progressive levels of cognitive development, from lower to higher order thinking skills. The assimilation of these two models links Technical Engineering lecturers' progressive levels of pedagogical technology integration with their students' progressive development of lower to higher order thinking skills (Puentedura, 2006, 2014). Hence, Table 3 offers a valuable framework for Technical Engineering lecturers to plan, evaluate and align their teaching strategies and learning outcomes, relative to their levels of technology integration.

Cultural-historical Activity Theory (CHAT) is a third generation expansion of Vygotsky's (1978, 1986) cultural historical theory legacy. According to Vygotsky (1978, 1986), culture and tools play important roles within human development and education. Vygotsky (1978) found that cognitive development can be achieved through the learning process, provided that teaching is directed at this development. The teaching approach of Vygotsky (1978, 1986) involves actively guiding a student's problem solving through 'mediation', i.e. a structured process in which the mediator (expert teacher/lecturer) is more competent than the novice student. What begins as a social relationship between the 'expert' and the 'novice', turns inwards and becomes owned by the novice. This process only occurs in a specific developmental space called the "zone of proximal development" that opens up between the expert and novice. This zone represents the difference between what a novice can achieve on her/his own (actual development), and the novice's potential level of development, i.e. what the novice can accomplish with the assistance of the expert (Hardman et al., 2018, p. 11). Leont'ev (1978, 1981), a co-worker of Vygotsky, developed Activity Theory, which distinguishes between three levels of human activity, i.e. operations, goal-directed actions, and motives. Furthering the ideas of both Vygotsky and Leont'ev, Yrjö Engeström (1987, 1995, 1999, 2001, 2007) developed cultural-historical activity theory (CHAT). CHAT can be used to analyse human actions and interactions within activity systems that are mediated by tools, which in 21st century technology-integrated learning environments, includes all digital devices and forms of electronic information that can be used to achieve learning outcomes (Murphy & Rodriguez-Manzanares, 2007).

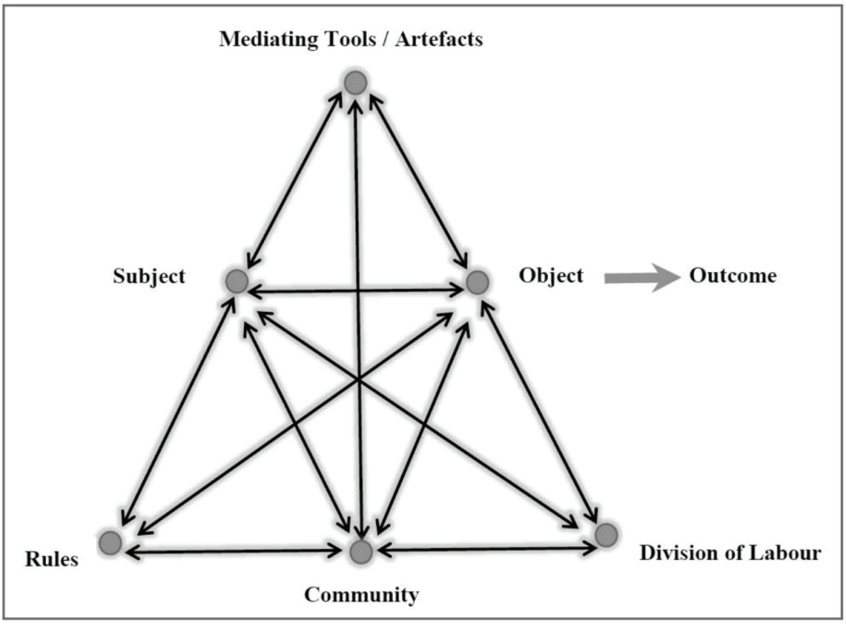

Figure 5: Engeström's (1999, 2001, 2007) 3rd generation Cultural Historical Activity Theory (CHAT)

Table 4: Generic descriptions of the various CHAT components, and what these components represent within the activity system of Technical Engineering lecturers' pedagogical practices

CHAT Components / Nodes	Generic Descriptions of CHAT Components	CHAT Components in the Activity System of Technical Engineering Lecturers' Pedagogical Practices
Subject	The subject of an activity system is the person, or group of people whose perspective is the focus of the analysis, e.g. a teacher or lecturers; group of learners or students.	Technical Engineering TVET lecturers
Object	The object is a problem space at which action is directed and transformed into an outcome, The object is the goal or motive of the activity system as a whole, but not necessarily that of individual members, e.g. improving learning, developing professional skills and knowledge, learner outcomes, etc.	Problem space at which action is directed and transformed to mediate the professional development of Technical Engineering students with cutting edge, industry-based 4IR technological and digital competencies
Mediating Tools / Artefacts	Tools or artefacts used to achieve the desired object, e.g. teaching strategies, the curriculum, and educational technologies. Both subject and object are influenced by mediating tools or artefacts. *Tools mediate between the subject and object.*	Aspects of industry-relevant 4IR technologies and digital tools used to mediate the professional development of Technical Engineering students. with cutting edge, industry-based 4IR technological and digital competencies
Community	Community to which the activity system belongs, e.g. both the teacher and learners; both the lecturer and the students	Both the Technical Engineering TVET College lecturer, and the students in her/his class
Division of Labour	Hierarchical power structures within the activity system, and also to the way in which labour is divided within the context of the system. *Mediates between the community and the object.*	Roles and division of labour within the Technical Engineering classroom community
Rules	Norms and rules of normal behaviour appropriate to the system that are understood by all members of the community. Define how participants are expected to behave, both implicit and explicit. Rules mediate between the subject and the community.	Both implicit and explicit norms and rules understood and accepted by both the Technical Engineering lecturer, as well as the students in the classroom community.
Outcome	Envisioned outcome of the successfully attained object	For the TVET College to yield Technical Engineering professionals with cutting edge Industry-relevant knowledge, technological skills and digital competencies, to fulfil the needs and demands of rapidly changing and digitally transforming 4IR industries.

Figure 5 visually illustrates Engeström's (1999, 2001, 2007) CHAT model, consisting of various component nodes, i.e. subject, object, community, mediating tools/artefacts, rules, and division of labour. Table 4 provides generic descriptions of the various CHAT components, and also explains how these apply to the activity system of Technical Engineering lecturers' 21st century pedagogical practices. The activity system dynamics of Technical Engineering TVET lecturers' pedagogical practices, are visually illustrated by Figure 6.

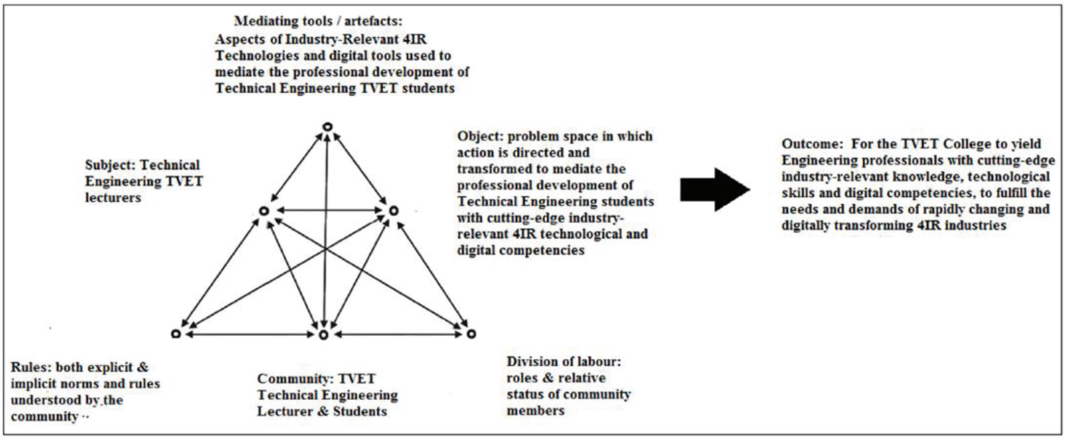

Figure 6: Activity System dynamics of Technical Engineering lecturers' pedagogical practices

An activity is embedded within a surrounding system, e.g. the integration and use of industry-relevant technologies is embedded in the activity system of Technical Engineering lecturers' pedagogical integration of technology in the classroom, which in turn, is embedded into the activity system of the TVET College. Within these embedded systems, the cultural life of the TVET College (or other setting) is developed and maintained. According to Leont'ev (1978, 1981), the central focus of the community's activities within an activity system, is to effectively achieve the object by means of various kinds of mediating tools and artefacts, e.g. industry-relevant emerging and advancing 4IR technologies and digital applications. It is important to clearly recognise and define the object of an activity system, however, it is not necessarily required for all participants in an activity system to always be fully aware of the object, e.g. it is not necessary for students in a Technical Engineering classroom community, to always be aware of the object of Technical Engineering lecturers' pedagogical practices. However, it is important for the subject (i.e. the Technical Engineering lecturer), to clearly identify and define the object (i.e. the professional development of students with cutting edge industry-relevant 4IR technological and digital competencies), towards which all pedagogical activities in the activity system are directed, and which is attained through the mediation of technological tools and digital applications.

According to Engeström (1987) and Leont'ev (1978), a central concern of their work is the conceptualisation of expansive learning, i.e. the capacity to interpret and expand the definition of the activity's object, and to respond to it in increasingly enriched ways. "Objects should not be confused with goals. Goals are primarily conscious, relatively short-lived and finite aims of individual actions" (Daniels, 2004:190). The object is the constantly reproduced purpose of a collective activity system that motivates and defines the horizon of possible goals and actions (Engeström, 1995; Leont'ev, 1978). "Expansive learning and enhanced professional practice occurs in activity settings that enable expansion of the object of activity. Expansive learning involves the creation of new knowledge and new practices for a newly emerging activity; that is, learning embedded in and constitutive of qualitative transformation of the entire activity system. Such a transformation may be triggered by the introduction of a new technology or set of regulations" (Daniels, 2004, p. 291). When technology is integrated and used as mediating tools in learning, it is required from Technical Engineering lecturers to make the shift from a traditional transmission-based approach to teaching and learning, to an approach that uses technology as a tool to mediate learning experiences that are transformative (Hardman et al., 2018).

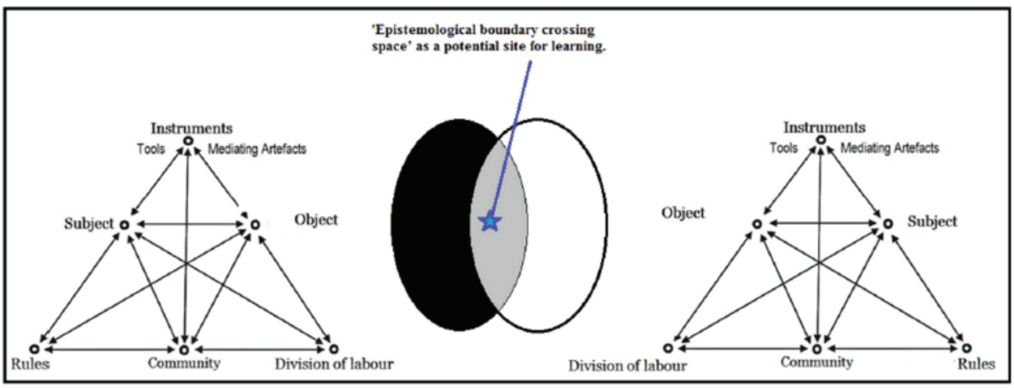

Figure 7: Epistemological boundary crossing space between activity systems is a potential site for learning

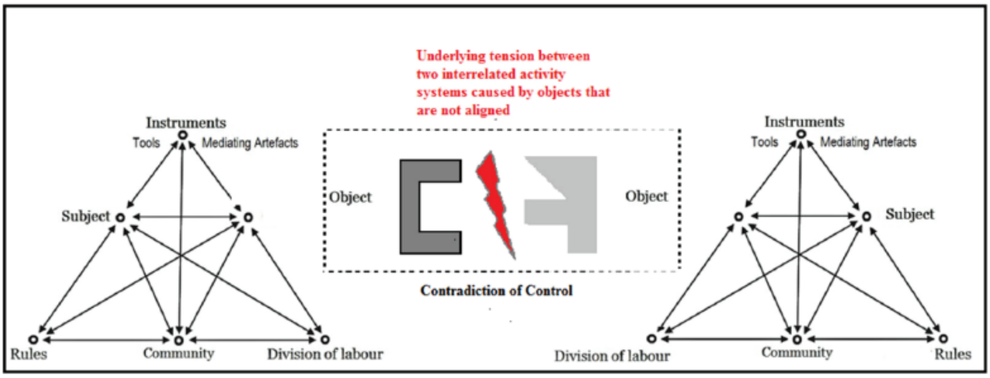

Figure 8: Underlying tension builds up between two juxtaposed activity systems when their objects are not aligned causing a contradiction of control

According to Engeström (2007), a researcher should always use two interdependent activity systems as a minimal unit of analysis. When the objects of two activity systems align, for example if a Technical Engineering lecturer and a student share the same objective, it creates an epistemological boundary crossing space, as a potential site for learning (Figure 7). However, when the objects of two interdependent activity systems are not aligned, it creates underlying tensions and conflict due to a contradiction of control (Figure 8). Such tension might hinder Technical Engineering lecturers in successfully integrating 4IR technologies in their pedagogical practices.

Researchers and Technical Engineering lecturers can use CHAT to explore and evaluate the inner dynamics of various activities and processes within the activity system of Technical Engineering lecturer's pedagogical practices, mediated through industry-relevant technologies and technological applications. The value of applying CHAT as an evaluation tool, is that it probes both the actual processes, as well as the activities of engaging with tasks within an activity system, rather than merely assessing the outcome.

Whether or not Technical Engineering lecturers are responding effectively to the 4IR's exponential digital transformation of industries, by continuously upskilling their technological skills and digital competencies, is not clear. Accordingly, this paper reports the empirical findings of a National survey that collected data from N=577 Technical Engineering lecturers at 52 TVET College campuses across South Africa that offer TVET Engineering study programmes. The purpose of the survey was to profile TVET Engineering Study lecturers' knowledge and pedagogical practices within engineering programmes across South Africa. The findings reported in this paper are from a sub-section of the survey that specifically probed into participants' awareness, understanding and practical skills in the use of discipline-specific technological advancements and digital educational enterprises, as to fulfil the need of creating and mediating industry-relevant learning opportunities for students in technology-integrated learning environments.

Research design and methodology

This paper reports selected findings from a research initiative (Teis & Els, 2021) that was mandated by the South African Department of Higher Education and Training (DHET) and funded by the European Union (EU). The overall purpose of this large-scale survey study was to determine the National profile of Technical Engineering lecturers at TVET Colleges across the Republic's TVET landscape, pertaining to their:

- Demographical information, e.g. gender, age group, programmes, employment status, etc.;
- Teaching qualifications and subjects. taught;
- Teaching and Industry-Based Work Experience
- Work-integrated learning, i.e. industry-based and school-based;
- Professional development; as well as
- Awareness, knowledge and competencies in the practical use or/and application of industry-relevant technological advancements in their fields of specialisation.

Of which selected empirical findings of the first and last, are reported in this paper.

Research design

A quantitative single cross-sectional survey research design was followed. A cross-sectional research design was best suited for the purpose of this National survey, which collected profiling data from a random stratified sample of N=577 Technical Engineering lecturers across South Africa, at a single point in time (Connelly, 2016). This National Survey is anchored within the Radical Structuralist social research paradigm (Burrell & Morgan, 1979), as it quantitatively investigated radical change in Technical Engineering lecturers' 4IR technological knowledge and skills, which is required to effectively reconstruct the curriculum of TVET Engineering Programmes.

Study population and sample

The study population of this National survey study included Technical Engineering lecturers of Engineering study programmes at TVET Colleges across South Africa's nine Provinces. From the total study population, a random stratified sample of N=577 Technical Engineering lecturers participated in the survey, representative of n=52 campuses of n=24 TVET Colleges.

Method of data collection: Survey instrument

A structured survey instrument was purposefully developed to collect empirical data for the profiling of Technical Engineering TVET lecturers. The development of the survey was informed by the following:

- Existing Educational Policies and Policy Frameworks (Department of Basic Education, 2018; Department of Education, 1997, 2004; Department of Higher Education and Training, 2013a, 2013b, 2015, 2017a, 2017b)
- The available corpus of knowledge pertaining to TVET research in South Africa (amongst others, Buthelezi, 2018; Makgato, 2019; McBride et al., 2009; Nundkumar & Subban, 2018; Papier, 2011; Papier & McGrath, 2008;

Papier et al., 2016; Perold et al., 2012; Teis, 2014; Terblanche & Bitzer, 2018; Timire, 2018).

- Discourses on TVET professional development (Papier & McGrath, 2008; Perold et al., 2012); as well as
- Research team members' participation in prior provisional development research projects (Mosia, 2017).

Survey items collected empirical data from Technical Engineering lecturers in the form of binary-scale responses (e.g. yes/no; male/female), Likert-scale type of responses (e.g. not at all / not so / somewhat / very / extremely), as well as filled-in information (e.g. Please write down your qualifications), that was also empirically captured as quantitative data.

Ethical considerations

Ethical clearance was obtained from both the UFS Research Unit (UFS-HSD2017/1487) and the Department of Higher Education and Training. Research applications were submitted to the Principals of TVET College campuses, and formal permissions were obtained from TVET Colleges to administer the survey on their campuses. An informed consent letter was sent out to Technical Engineering lecturers on all TVET College campuses. Participation in the survey study was anonymous and voluntary. Participants were treated with respect, and were informed about their right to withdraw from the research process at any time or stage.

Funding

This publication has been developed through the Teaching and Learning Development Capacity Improvement Programme which is being implemented through a partnership between the Department of Higher Education and Training and the European Union.

Data collection

The research team engaged with regional TVET College management and Technical Engineering lecturers in order to contextualise and plan the data collection process, in terms of access, availability and participation, to ensure that data would be collected according to high ethical standards, and that data collection would not interfere with or disrupt the normal academic activities at TVET Colleges. Data collection started in July 2017 and ended in August 2019. Arrangements were made for a suitable date and time to administer the survey on each campus. Participating researchers were identified on the various TVET campuses to administer the survey to Technical Engineering lecturers, and to submit the completed surveys, signed consent forms and attendance registers to a central office at the University of the Free State. The survey responses of Technical Engineering lecturers were digitally captured in a combined quantitative dataset, and was prepared for statistical data analyses.

Statistical analyses

The statistical software SPSS® was used to calculate both descriptive statistics (frequencies and frequency percentages), as well as inferential statistics (cross-tabulations) on the combined dataset. However, for the purpose of the current discussion, only descriptive statistical findings are reported in this paper.

Demographical information of the sample

In total, 850 surveys were distributed to Technical Engineering lecturers on 46 campuses at 24 TVET Colleges across all nine Provinces of South Africa. A random stratified sample of N=577 Technical Engineering lecturers successfully completed the survey instrument, signifying a survey return rate of 67.88%.

Provincial distribution

Frequency Table 5 reports on the provincial and TVET College distribution of the total sample (N=577) of participating Technical Engineering lecturers.

Table 5. Provincial and TVET College distributions of the total sample (N=577)

	Frequencies (n)	Frequency %
North-West	**15**	**2.6**
Taletso TVET College	10	1.7
Vuselela TVET College	5	0.9
Kwa-Zulu Natal	**85**	**14.7**
Majuba TVET College	85	14.7
Western Cape	**105**	**18.2**
Boland College	7	1.2
College of Cape Town	6	1.0
False Bay College	30	5.2
Northlink College	47	8.1
South Cape TVET College	15	2.6
Northern Cape	**42**	**7.3**
Northern Cape Rural TVET College	11	1.9
Northern Cape TVET College	11	1.9
Northern Cape Urban TVET College	20	3.5
Free State	**79**	**13.7**
Maluti TVET	21	3.6
Motheo TVET College	31	5.4
Flavious Mareka	27	4.7
Eastern Cape	**92**	**15.9**
East-Cape Midlands College	32	5.5
Ikhala TVET College	7	1.2
Ingwe TVET College	31	5.4
King Sabatha Dalindyebo College	22	3.8
Mpumalanga	**47**	**8.1**
Gert Sibande TVET College	20	3.5
Nkangala TVET College	10	1.7
Ehlanzeni TVET College	17	2.9
Limpopo	**50**	**8.7**
Capricorn TVET College	32	5.5
Vhembe TVET College	18	3.1
Gauteng	**62**	**10.7**
Tshwane South TVET College	62	10.7
Total Sample (N) =	**577**	**100.0**

The province most represented in the total sample, is the Western Cape with n=105 participants, i.e. 18.2% of the total sample; while the province least represented was the Northern Cape with n=42 participants, i.e. 7.3% of the total sample.

College distribution

Amongst the n=24 TVET Colleges that participated in the survey, Majuba TVET College is most represented by n=85 participants (14.7% of the total sample), while Vuselela TVET College is least represented by n=5 participants (0.9% of the total sample).

Gender and age group distributions

Frequency Table 6 shows the gender and age group distributions of the total sample (N=577).

Table 6: Gender and age group distributions of the total sample (N=577)

Gender	Frequencies (n)	Frequency %
Female	137	23.7
Male	431	74.7
Did not indicate	9	1.6
Total Sample (N) =	**577**	**100.0**
Age Groups	**Frequencies (n)**	**Frequency %**
25 years or younger	10	1.7
26-30	73	12.7
31-35	105	18.2
36-40	103	17.9
41-45	95	16.5
46-50	54	9.4
51-55	54	9.4
56-60	33	5.7
61 years or older	34	5.9
Did not indicate	16	2.8
Total Sample (N) =	**577**	**100.0**

The gender distribution of the total sample (N=577) comprises of n=431 (74.7%) males and n=137 (23.7%) females. It remains unclear why n=9 (1.6%) of the total sample decided not to indicate their gender group. Could theses non-responses possibly be a form of resistance against gender stereotyping or marginalisation? Or did participants refrain from reporting their gender out of fear that this could, for some reason, negatively impact them? Gender identity and gender related issues of Technical Engineering lecturers, for the most part, still remain unexplored and require the attention of future research. The gender distribution reported for the current study's sample of participants, i.e. 74.6% male and 23.7% female, corresponds very well with the gender percentages reported by merSETA (2019, p. 25) for the manufacturing sectors, i.e. 76% male and 24% female. It is evident from the resounding similarity of gender distribution percentages in both studies, that the size of the current study’s random stratified sample was large enough for data to become saturated, and to adequately reflect the larger South African population of TVET lecturers within the Engineering disciplines.

Most of the participants indicated that they were in the age groups 31 to 35 years of age (n=105; 18.2% of the total sample) and 36 to 40 years of age (n=103; 17.9% of the total sample). The age group least represented in the total sample are lecturer who falls within the age range 25 years or younger (n=10; 1.7%). Again, one could merely speculate on possible reasons why n=16 (2.8%) of the total sample did not report their age group.

Programmes distribution

When participants were asked to indicate their programmes, 47.5% (n=274) of the total sample (N=577) indicated their 1st programme as the National Accredited Technical Education Diploma (NATED), 35.5% (n=205) indicated the National Certificate: Vocational Programme (NCV), while 17% (n=98) did not disclose their 1st programme (Frequency Table 7). Furthermore, 13.5% (n=78) indicated NATED, and 17.9% (n=103) Skills, as their 2nd programme, while 68.6% (n=396) did not indicate a second programme, as most lectures only teach in one of the three TVET programmes.

Table 7: Programme distribution of the total sample (N=577)

		1st TVET Programme	2nd TVET Programme
National Accredited Technical Education Diploma (NATED) programme	Frequencies (n)	274	78
	Frequency %	47.5	13.5
National Certificate: Vocational (NCV) programme	Frequencies (n)	205	
	Frequency %	35.5	
Skills	Frequencies (n)		103
	Frequency %		17.9
Did not indicate	Frequencies (n)	98	396
	Frequency %	17.0	68.6
Totals	n	577	577
	%	100.0	100.0

As previously mentioned, the Department of Higher Education, Science and Innovation, supported by CISCO Systems, Inc., developed digital skills training, which has been integrated into the National Certificate (Vocational) [NCV] programme (Nzimande, 2021, Online). Therefore, 35.5% (n=205) of the total sample received digital skills training, which has been integrated into the NCV programme, after their participation in the current survey. The department is also introducing a new Robotics stream in the NCV programme in 2022, with subjects covering the automation of industries by robotics (Nzimande, 2021, Online). Minister Nzimande (2021, Online) furthermore anticipated a reduction in the offering of NATED programmes at TVET colleges, following the expected June 2021 completion of the curriculum reconstruction of engineering programmes.

1st Subject categories

The total group of participants specified n=90 different first subjects they teach. A possible explanation for the large variety of reported subjects might be that TVET Colleges are catering for different industries, for which different subjects are required. On the other hand, the large number of reported first subjects (n=90) could also possibly signify that the theoretical and practical quality of Technical Engineering subjects, within NATED and NCV programmes offered by TVET colleges across South Africa, is at risk of being jeopardised, due to none-standardised subjects. In order to address tangible categorical incoherencies and to increase the construct validity of reported first subjects, the research team reduced the number of reported first subjects (n=90) by categorising them into eight categories of subjects. Accordingly, frequency Table 8 reports the findings pertaining to the eight subject categories in which participants teach their first subjects.

Table 8: Subject categories in which participating TVET lecturers teach their first subject

Subject Categories	Frequencies (n)	Frequency %
Sciences	124	21.5
Electrical Engineering	150	26.0
Mechanical Engineering	145	25.1
Drawing/Drafting	29	5.0
Civil Engineering	73	12.7
ICT	12	2.1
Other	14	2.4
Skills Programme	8	1.4
Did not indicate	22	3.8
Total Sample (N) =	**577**	**100.0**

Amongst the N=577 Technical Engineering lecturers who participated, 26% (n=150) indicated that the first subject they teach is an Electrical Engineering subject, 25.1% (n-=45) a Mechanical Engineering subject, and 21.5% (n=124) a Science subject. Furthermore, 12.7% (n=73) taught a Civil Engineering subject as their first subject, 5% (n=29) a Drawing/Drafting subject, 1.4% (n=8) a Skills Programme subject, 2.1% (n=12) an ICT subject, and 2.4% (n=14) another subject. Twenty-two participants (3.8% of the total sample) did not indicate the first subject they teach. As already mentioned, the DHET commenced with the reconstruction of the curriculum of Engineering programmes in August 2020, which is anticipated to be completed by June 2021 (Nzimande, 2021, Online). As the fields of Electrical Engineering, Mechanical Engineering, and Civil Engineering are being prioritised, the current curriculum reconstruction of engineering programmes will directly impact 63.8% (n=368) of the first subjects taught by the total sample of participants in the current investigation. Twenty-three percent (23.4%; n=135) of participating Technical Engineering lecturers reported that they were not teaching their first subjects; 62.2% (n=359) indicated that they were teaching their first subjects, while the majority of participants (85.6%; n=494) did not respond to this survey item.

Participants' formal teaching qualifications for the 1st subjects they teach

According to the findings reported in frequency Table 9, 40.9% (n=236) of the total sample of participants (N=577) indicated that they do have formal teaching qualifications pertaining to the 1st subject they teach, 37.3% (n=215) indicated no formal teaching qualification for their 1st subject, one participant indicated VEOP, while 21.7% (n=125) did not respond to the survey question.

Table 9: Participants' formal teaching qualifications for the 1st subject they teach, as well as whether or not in-service training content enriched their teaching capabilities

Formal Teaching Qualification	Frequencies (n)	Frequency %
Did not indicate	125	21.7
Yes	236	40.9
No	215	37.3
VEOP	1	0.2
Total Sample (N) =	**577**	**100.0**
Did in-service training content enriched teaching capabilities	**Frequencies (n)**	**Frequency %**
Did not indicate	2	0.3
No	266	45.7
Yes	311	53.9
Total Sample (N) =	**577**	**100.0**

When asked whether or not in-service training content enriched their teaching capabilities, in keeping with new knowledge and skills, 53.9% (n=311) of the participants indicated Yes, while 45.7% (n=266) indicated No (frequency Table 9). It should be noted, however, that the 45.7% of participants who indicated that their teaching capabilities were not enriched by in-service training, also includes the 28.1% of participants who reported that they did not do any in-service training.

Empirical results and discussion of findings

The empirical findings from a sub-section of the survey that requested participants to self-rate their awareness, knowledge and competence in the practical use and/or application of industry-relevant 4IR technological developments/advancements, are reported in this section.

Participants' self-rated awareness of 4IR technological developments within their areas of specialisation

One of the survey items specifically requested Technical Engineering lectures to indicate whether or not they are aware of any technological developments/advancements in their areas of their specialisation.

Table 10: Participants' self-rated awareness of 4IR technological developments/advancements within their areas of specialisation

Awareness of technological developments / advancements in their area of specialisation	Frequencies (n)	Frequency %
Unaware of any technological developments/advancements in their area of specialisation	302	52.3
Aware of technological developments/advancements in their area of specialisation	217	37.6
Did not indicate	58	10.1
Total Sample: N =	**577**	**100.0**

Of the total sample (N=577), 37.6% (n=217) indicated that they were aware of technological developments/advancements in their areas of specialisation, 52.3% (n=302) indicated that they are unaware of any technological developments/advancements. This could contribute towards their professional development of technological literacy and digital competencies that are required for 21st century technology-integrated learning environments that are industry-relevant (frequency Table 10).

The next survey item requested from participants to: Please specify any three of these technological developments that you are aware of that are in your area of specialisation. Table 11 shows n=76 randomly selected examples of some of the technological developments that Technical Engineering lecturers specified as 4IR technologies within their areas of specialisation, in response to the survey item. Correctly specified 4IR technological developments are shaded in Table 11.

Table 11: Random examples of some of the 4IR technological developments that Technical Engineering lecturers specified within their areas of specialisation

3D Printers	**GPS**
Alternating Current (AC) Motor drives	Hydraulics
Advanced ARC Welding	**In computer aided manufacturing and 3D**
Air-conditioning	**Integration of automation devices**
Artisan training	Internet
Assessor	Isolators
Auto electrical qualification (Trade test)	Joint and termination
AUTOCAD Software integration and training	Knowledge of other languages in equipment mandarin
Automation, Mechatronics, robotics, diagnostics, troubleshooting	LED Lightning systems
Blended Learning	Linux operation systems
Boilermakers specialist	Machining, Phoning and videos
Brakes, Brakes by wire, Braking systems	**Mechatronics (Automation)**
Change on natural standards	Microsoft Word
Chemical	Moderator course
Cloud	New pipes , New pipe fittings
Component development	New trade test for electricians
Computer	Plumbing
Computer based fault finding rather than manual / human fault finding	Pneumatics
Computer skills and machine exposure	Power steering
Computerised programs	Power tools
Curriculum change in artisan development	Project management
Daylight switches	Quantity surveyor
Design methods	**Remote operations**
Development	Renewable energies, Solar and Wind
Development and implementation of electrical power systems simulators	Schematichydranlic circuit on computer
Digital electrical measuring instruments- kwh meters	Sequence starters
Drain camera	Setting of question papers
E-Books	**Smart electrical grids**
Education technology	Soldering techniques
E-Learning	Spreadsheet
Electrical	Steering and accelerator shaft and pedal developments
Electrical and diagnostic advancement software	Surveyor land total station
Electricity	Test equipment- Oscilloscope
Emission control systems	**Toilets that uses sense devices**
Energy recovery braking systems	Twizza soft drinks
Fibre concrete	Unit standard need to be revisited for the sake of relevancy
Film and media studies	Water based paints
Geysers	Woodwork- Kitchen installation

Note: Correctly specified examples of 4IR technologies are shaded

Although 37.6% (n=217) of the total sample of participants indicated that they were aware of technological developments/advancements in their areas of specialisation (Table 10), when asked to provide actual examples of such technologies, only 17.12% of the examples that participants provided (Table 11), were real examples of industry-relevant 4IR technological developments/advancements. It therefore seems that participants overrated their actual awareness of technological developments/advancements within their areas of specialisation with 20%.

Participants' self-rated knowledge of the practical use and/or application of 4IR technological developments / advancements within their areas of specialisation

The survey also requested of participants to self-rate their knowledge of the practical use and/or application of 4IR technological developments/advancements.

Table 12: Participants' self-rated knowledge of the practical use and/or application of 4IR technological developments/advancements

Self-rated knowledge about the practical use and/or application of 4IR technologies	Frequencies (n)	Frequency %
Not at all knowledgeable	22	3.8
Not so knowledgeable	36	6.2
Somewhat knowledgeable	99	17.2
Very knowledgeable	107	18.5
Extremely knowledgeable	24	4.2
Did not indicate	289	50.1
Total Sample: N =	**577**	**100.0**

Of the total sample of participating TVET lecturers, 18.5% (n=107) rated themselves as very knowledgeable about the actual/practical use and/or application of the technological developments/advancements, 4.2% (n=24) rated themselves to be extremely knowledgeable, while 17.2% (n=99) consider themselves to be somewhat knowledgeable (frequency Table 12). Only 3.8% (n=22) indicated that they do not have any knowledge about the actual/practical use and/or application of such technological developments/advancements, while 6.2% (n=36) consider themselves not so knowledgeable. Fifty percent (n=289) of the total group of participants, however, did not respond to this survey question to rate their own knowledge in this regard.

Participants' self-rated competence in the practical use and/or application of 4IR technological developments / advancements within their areas of specialisation

Table 13: Participants' self-rated competence in the practical use and/or application of the technological developments/advancements

Self-rated competence in the practical use and/or application of 4IR technologies	Frequencies (n)	Frequency %
Not at all competent	20	3.5
Not so competent	39	6.8
Somewhat competent	87	15.1
Very competent	107	18.5
Extremely competent	26	4.5
Did not indicate	279	48.4
Total Sample: N =	**577**	**100.0**

With regards to participants self-rating of their own competence in the actual/practical use and/or application of these technological developments/advancements (frequency Table 13), 18.5% (n=107) rated themselves as very competent, and only 4.5% (n=26) viewed themselves as extremely competent. Furthermore, 6.8% (n=39) rated themselves as not so competent, while 3.5% (n=20) indicated that they are totally incompetent in the actual/practical use and/or application of these technological developments/advancements. One could merely speculate on a possible reason why 48.4% (n=279) of the total number of N=577 participants refrained from self-rating their competence in the practical use and/or application of technological advancements in their areas of specialisation. However, considering that 48.4% of the participants disregarded this test item, and that only 17.12% of participants were able to provide examples of actual 4IR technologies in their fields of specialisation (Table 11), it seems to lean more in favour of surmising such non-responses to also be indicative of participants' incompetence in the practical use/application of 4IR technological developments/advancements.

Summary of empirical findings

The empirical findings revealed that 52.3% of participating technical engineering lecturers are unaware of any technological advancements within their area of specialisation, and that they also do not know what the potential impact of such technological advancements might be on future technical training. Notwithstanding the finding that 37.6% of the lecturers indicated that they were aware of technological developments/advancements in their areas of specialisation, when asked to provide actual examples of such technologies, only 17.12% of the examples that participants provided, were real examples of industry-relevant 4IR technological advancements, suggesting that participants overrated their actual awareness of 4IR technological advancements with 20%. Only 23% of the lecturers rated themselves as competent in the practical use and/or application of 4IR technological advancements, while 48.4% refrained from rating their competence in the practical use of 4IR technologies. These findings suggest that the vast majority of South African Technical Engineering TVET lecturers is lacking the necessary competence in 4IR technological knowledge and skills, which is required to effectively reconstruct the curriculum of TVET Engineering Programmes, and to sufficiently prepare their students for the growing demands set by industries.

Conclusions and recommendations for future research

This paper is in support of the Department of Higher Education, Science and Innovation's current reconstruction of Engineering programmes offered at TVET colleges, in order to align and make them responsive to the rapidly changing needs of industries. The 4IR's exponential digital transformation and automation of industries is increasingly raising the complexity of knowledge and skills required for entry-level positions in industries. Subsequently, Technical Engineering lecturers are mandated to continuously upskill their knowledge and skills in the practical application of the latest industry-relevant 4IR technological advancements within their areas of specialisation, and to effectively integrate these into their pedagogical practices. Technical Engineering lecturers should become experts within their fields of specialisation, in order to mediate their students effectively to develop, not only theoretical knowledge, but also applicable digital skills and hands-on technological capabilities, that industries will demand from them at entry-level positions. To accomplish this, Technical Engineering lecturers must shift their pedagogical approach from a transmission-based approach to a transformative-based approach, in which technology is interwoven and used as a mediating tool to create 21st century transformative learning experiences for their students in technology-integrated learning environments that are industry based Accordingly, this paper provides valuable guidelines for Technical Engineering lecturers on how to integrate industry-relevant technologies and digital competencies in their pedagogical practices progressively, to achieve 21st century learning outcomes This paper also shows how Technical Engineering lecturers can progressively mediate the development of higher-order thinking skills and digital savviness among their Engineering students, relative to their respective levels of technology integration.

As already mentioned, the DHET commenced with the reconstruction of the curriculum of Engineering programmes in August 2020, which is anticipated to be completed by June 2021 (Nzimande, 2021, Online). As the fields of Electrical Engineering, Mechanical Engineering, and Civil Engineering are being prioritised, the current curriculum reconstruction of engineering programmes will directly impact 63.8% (n=368) of the first subjects taught by the total sample of participants in the current investigation.

The management of TVET institutions, for the most part, still seem reluctant to fully capitalise on the potential benefits and growth that could be gained from 4IR technology’s fertile disruption and transformation of organisations and industries (Renjin, 2019). It is therefore not surprising that the empirical findings reported in this paper show that, at the time of their participation in the national survey, 52.3% (n=302) of the N=577 Technical Engineering lecturers, were unaware of any technological advancements within their area of specialisation, and also did not know what the potential impact of these might be on future technical training. Since their participation in the survey between July 2017 and August 2019, 35.5% (n=205) of the Technical Engineering lecturers in the current investigation received digital skills training, which has been integrated into the NCV programme

(Nzimande, 2021, Online). The findings reported in this paper that relate to Technical Engineering lecturers' awareness, knowledge and competence in the practical use and/or application of industry-relevant 4IR technological developments/advancements. The findings therefore offer a valuable point of reference for the Department of Higher Education, Science and Innovation against which to compare the effectiveness/success of the digital skills training that was implemented after August 2019 for Technical Engineering lecturers in the NCV programme.

TVET Colleges will have to invest in establishing the necessary infrastructure that is required for Technical Engineering lecturers to successfully integrate industry-relevant 4IR technologies into their pedagogical practices in technology-integrated learning environments. This will require not only investment in technology hardware and software, but also provide applicable training opportunities for IT staff and lecturers to be able to integrate and use 4IR technologies effectively in order to deliver 21st century industry-based learning opportunities to students. It is crucial that the management of TVET colleges and Technical Engineering lecturers share the same objective, i.e. the professional development of Technical Engineering students with cutting-edge industry-relevant 4IR technological and digital competencies, in order to avert underlying tensions between the two activity systems, resulting from a contradiction of control.

Some of the pivotal questions that still require the attention of future research, include:

- How can the management of TVET Colleges sufficiently support Technical Engineering lecturers in establishing effective industry-relevant 4IR technology-integrated learning environments and learning opportunities for their students?
- What digital open resources, applications, and media platforms are readily available to continuously keep Technical Engineering lecturers updated on

the latest trends and technological advancements within their fields of specialisation?

- What are the possible reasons why TVET lecturers are not currently utilising the extensive open source learning materials that are available via the DHET Lecturer Support System Portal?
- What continuous professional development opportunities can be created for Technical Engineering lecturers with regard to the effective integration, application and utilisation of advancing and emerging technologies in their teaching of Technical Engineering subjects?
- Is the digital skills training that was recently integrated into NCV programme, which relates to knowledge of the use of the internet, email, cyber security and databases, sufficiently garnering Technical Engineering lecturers with the required technological skills and digital competencies to integrate and use aspects of 4IR technologies as part of their pedagogical practices effectively?
- Is the digital skills training that was recently integrated into NCV programme, which relates to knowledge of the use of the internet, email, cyber security and databases, sufficiently preparing Technical Engineering students for the high demands of advancing technological driven 4IR Industries?
- What professional development opportunities can be developed and offered to Technical Engineering lecturers within the NCV programme, in order to sufficiently upskill and prepare them with the necessary industry-relevant digital competencies and technical skills in robotics and industrial automation required for the implementation of the new NCV Robotics stream in 2022.

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