
Knowledge, competencies and dispositions of lecturers in Technical Engineering in the context of advancing 4IR technologies

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ABSTRACT

The advent of the Fourth Industrial Revolution (4IR) affirms that the transformation and advancement of all industries and society are progressively driven by emergent and rapidly changing technologies. In order to help establish a technologically literate society, it is crucial for lecturers in Technical Engineering to stay abreast of the latest trends and technological advancements in their area of specialisation. This article reports on the findings of a sub-section of a nationwide survey that collected data from lecturers in Technical Engineering at 52 TVET college campuses across South Africa ($n = 577$) that offer TVET Engineering Study programmes. The purpose of the survey was to profile TVET Engineering Study lecturers' knowledge and pedagogical practices in engineering programmes across South Africa. The sub-section of the survey specifically probed the participants' awareness and understanding of discipline-specific technological advancements and digital educational enterprises, and also the potential impact of these on teaching technical subjects. The findings show that 52,3% ($n = 302$) of the participating lecturers in Technical Engineering are unaware of any technological advancements in their area of specialisation and that they do not know what the potential impact of this might be on future technical training. When Engeström's Cultural Historical Activity Theory (CHAT model) is applied to the activity systems that are involved, the underlying tension between these systems is revealed. This article examines the possible implications of these findings for the renewal of the Technical Engineering curriculum, considering that these lecturers demonstrate limited awareness of the technological advancements needed to participate effectively in the 4IR era.

KEYWORDS

TVET lecturers, engineering disciplines, emerging technologies, technology-integrated learning environments, CHAT model

Orientation and problem statement

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:np).

Technological 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, Klein, Portsmore & Rogers, 2008). Mbanga and Mtembu (2020) note further that even though TVET lecturers perceive the incorporation of digital tools in teaching and learning practices as convenient and useful, training is required to implement the relevant technologies effectively in classes. The 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 United States prefers *Industrial Internet Consortium*, whereas in Japan and Asia the term used is the *Industrial Value-Chain Initiative (IV-I)*. However, according to Philbeck and Davis (2019:17), *Industry 4.0* refers to a specific component within the larger concept of the 4IR, which focuses specifically on the relationship between digitisation, organisational 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, 2019:17). 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, 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:np).

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.

Literature review

Cyber-physical system (CPS) design architecture

There has been a significant shift in advanced economies from manufacturing to services driven by information and technology (ICT). Industrial and manufacturing processes are being automated aggressively, owing 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 has accelerated the automation of industries even more (Marr, 2020). Yokogawa (2021:np) postulates various levels of industrial automation, ranging from the lowest level of autonomy, in which all industrial and manufacturing processes are still manually controlled by human beings, 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 industrial transition stages resemble the two phases of the technological revolutions: the Industrial Automation stage dominated by a Third Industrial Revolution (3IR) technology interphase and an Industrial Autonomy stage (4IR). We argue that the shifts from manually controlled manufacturing and production processes to the autonomous operation of multi-collaborating ecosystems are critical to the knowledge lecturers in Technical Engineering need for the development of industry-relevant curricula.

The rapid digitisation and automation of industries, however, has also brought new challenges for future labour markets and technical education and training. Automated systems are constantly raising the complexity of tasks, which in turn demand incessantly 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; this is due to the continuous digital automation and transformation of industries. Makgato (2019:390) voices 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 in order to sustain the growing and ever-changing demands brought about by the digital transformation of 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 ... 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 (South Africa, 2019:np).

TVET colleges, as 'significant and necessary participants' in the 4IR (Nundkumar & Subban, 2018:309), have aspired to fulfil these demands. Nzimande (DHET, 2017) acknowledges the 4IR as an opportunity to speed up economic development and advance skills for industrialisation, and mandated TVET colleges to produce individuals who can embrace the change brought about by technology.

In his 11 February 2021 parliamentary reply to a question raised in the National Assembly, Minister Nzimande (2021) reported:

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.

New programme development

The Department of Higher Education, Science and Innovation (DHESI), supported by CISCO Systems, Inc., a US multinational technology conglomerate,

developed digital skills training, which has been integrated into the National Certificate (Vocational) [NCV] programme. The new programme stream focuses 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).

The DHESI further collaborated with the Quality Council for Trades and Occupations (QCTO) in reconstructing curricula for Engineering Studies programmes to align them with industry needs and the standards of professional bodies. The programmes that have been prioritised and are currently being reconstructed are those in the following fields: Electrical Engineering, Electronics Engineering, Mechanical Engineering and Civil Engineering. The

curriculum reconstruction of the engineering programmes commenced in August 2020 and it is anticipated that it will be completed by June 2021. The completion of this process will see a reduction in the offering of the current National Accredited Technical Education Diploma (NATED) programmes and a shift to occupational programmes which are more industry-aligned. Since 2018, the curricula of 38 subjects in the NATED programmes covering Engineering, Business and Services studies have been updated. The implementation of these revised and/or updated curricula started in January 2021 (Nzimande, 2021). The minister appealed to the management of Higher Education Institutions (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 (Nzimande, 2020:np).

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:np).

In order for lecturers in Technical Engineering to be able to ‘command the best experiences from related industries’ and to ‘provide good experiential learning opportunities for students’, they need to keep abreast of the latest trends and technological advancements in their fields of specialisation.

Professional development

Lecturers in Technical Engineering are mandated to be experts in their fields of specialisation and to mediate effectively the professional development of their novice students (DHET, 2013). This should be done in order to gain not only theoretical knowledge, but also the applicable digital skills and hands-on technological capabilities that industries will require of them. Even so, until recently, almost nothing was known about the level of awareness lecturers in Technical Engineering at TVET colleges had either of industry-relevant technological advancements in their areas of specialisation or about their knowledge and practical skills in the pedagogical use or/and application of those technologies (Teis & Els, 2021). Mbanga and Mtembu (2020) have noted further that even though lecturers at TVET colleges perceive the incorporation of digital tools in teaching and learning practices as convenient and useful, they require training in implementing the relevant technologies effectively in classes. It is also unclear whether or not these lecturers are actually considering the transformative impact that emerging technologies will have on their teaching practices in future. Accordingly, this article reports on the empirical findings of a sub-section of a national survey 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 lecturers in Technical Engineering to:

- 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 discipline-specific transformative learning experiences;
- integrate industry-relevant technologies and digital competencies progressively into their pedagogical practices in order to achieve 21st-century learning outcomes.

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

Theoretical underpinnings

Continuous professional development of technological literacy and digital competencies

Twenty-first-century skills are the abilities required in order to be effective workers, citizens and leaders in the global economy (Madhav, Simelane-Mnisi, Hardman, Dlamini & Lilley, 2018). The shift towards an autonomously operating multi-collaborative ecosystem is characterised by a decentralised decision-making, information-sharing, teamwork and innovation-driven process (Binkley, Erstad, Herman, Raizen, Ripley, Miller-Ricci & Rumble, 2012). These perspectives imply that people need to know how to use their acquired skillsets by thinking critically, applying knowledge to new situations, analysing information, comprehending new ideas, communicating, collaborating, solving problems and making decisions (Partnership for 21st-Century Skills, 2008). Anyone familiar with the literature of technical education over the past decade should agree that a shared and deeper understanding of technological literacy as the intended outcome of education in Technical Engineering has proved to be unexpectedly complex. According to Dakers (2018:23), being technologically 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, as a component of technological literacy in the 4IR era, cannot be assessed in terms of right or wrong: one is always in the process of becoming more technologically literate and more digitally competent (Dakers, 2018:23). 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 for 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 (Stommel, 2013; Burtis, 2016; Hardman, Molotsi, Lilley, Madhav, Simelane-Mnisi & Dlamini, 2018). Teis (2014:66) characterises learning experiences in a rapidly changing digital age as those

that combine rigorous academic study and the excitement of discovery ... supported by an intellectual stimulation of a diverse group of similar eager learners.

Mapotse (2014) supports such a focus on knowledge production in technical engineering in his call for technical education to adopt a critical approach to knowledge development, placing learners at the centre of the learning process.

Lecturers' knowledge of Technical Engineering

The Technological Pedagogical Content Knowledge (TPACK) model, first proposed by Koehler and Mishra (2006), forms a critical part of the Department of Basic Education's (2018) *Professional Development Framework for Digital Learning*. The TPACK model emphasises that 21st-century teaching has become a highly complex activity that embraces various kinds of knowledge. The TPACK model is an effective tool for advancing these lecturers' thinking about teaching. De Miranda (2008), who argued further that teacher knowledge frameworks enable teachers to design the best learning experiences to teach, supports this view. A teacher's understanding of effective teacher knowledge frameworks could shift their focus from *what to teach* to *an understanding of the discipline-specific strategies* to bring about the best learner experiences in a coherent manner. The TPACK model could serve as a tool to illuminate the complex interplay of various types of knowledge that lecturers in Technical Engineering need to acquire and integrate as part of their 21st-century pedagogical practices (Hardman et al., 2018). We demonstrate these complexities in Table 1 below, through an analysis of the required teacher knowledge frames and thinking skill taxonomies. Table 1 outlines the critical models of knowledge that Technical Engineering lecturers must possess in advanced technological teaching environments.

Table 1: Linking lecturers in Technical Engineering SAMR (Substitution-Augmentation-Modification-Redefinition) 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 students of Technical Engineering (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
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
	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 with the use of technology	Evaluate	Experimenting, hypothesising, testing, monitoring, critically evaluating, reviewing, posting, moderating, virtually collaborating and networking with experts in the field
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	Analyse	Comparing, organising, deconstructing, attributing, outlining, finding, structuring, integrating, linking, validating, cracking, reverse engineering
	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	Apply	Implementing, carrying out, using, executing, loading, playing, operating, hacking, uploading, sharing, editing
Substitution		Understand	Interpreting, summarising, inferring, paraphrasing, classifying, categorising, comparing, explaining, exemplifying, advanced 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

Pedagogical integration and use of industry-relevant technologies by lecturers in Technical Engineering

The levels of integration of technology proposed by Puentedura's (2006; 2014) *Substitution-Augmentation-Modification-Redefinition (SAMR)* model offer lecturers in Technical Engineering the opportunity to self-evaluate and determine their progressive levels of pedagogical technology integration, that is, from the lowest *Substitution* level, to *Redefinition* as the highest level of integration (first two columns of Table 1). The SAMR model could help these lecturers 'to consider how to take full advantage of the benefits of emerging technologies' (Hardman et al., 2018:27). The first two integration levels, *Substitution* and *Augmentation*, denote the enhancement of teaching and learning through the use of technology; whereas the third and fourth levels of integration, *Modification* and *Redefinition*, epitomise the tangible transformation from traditional to 21st-century technology-integrated teaching and learning practices (Puentedura, 2006; 2014). The second column in Table 1 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 third and fourth columns of Table 1, representing progressive levels of cognitive development, from lower- to higher-order thinking skills. The assimilation of these two models links the lecturers' progressive levels of pedagogical technology integration to their students' progressive development of lower- to higher-order thinking skills (Puentedura, 2006; 2014). Therefore, Table 1 offers a valuable framework for lecturers in Technical Engineering to use in order to plan, evaluate and align their teaching strategies and learning outcomes relative to their levels of technology integration.

Activity system of Technical Engineering lecturers' pedagogical practices

The Cultural-Historical Activity Theory (CHAT) is a third-generation expansion of Vygotsky's (1978; 1986) cultural-historical theory legacy in which culture and tools play important roles in human development and education. Vygotsky (1978) found that cognitive development can be achieved through a learning process provided that teaching is directed at this development. This teaching approach (Vygotsky, 1978; 1986) involves actively guiding a student's problem-solving through 'mediation', that is, 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 occurs only in a specific developmental space called the 'zone of proximal development' that opens up between the expert and the novice. This zone represents the difference between what a novice can achieve on their own (actual development) and the novice's potential level of development – what the novice can accomplish with the assistance of the expert (Hardman et al., 2018:11). Leont'ev (1978; 1981), a co-worker of Vygotsky's, developed the Activity Theory, which distinguishes between three levels of human activity: operations, goal-directed actions and motives. Developing 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 the digital devices and forms of electronic information that can be used to achieve learning outcomes (Murphy & Rodriguez-Manzanares, 2007). Vygotsky's CHAT model could be used as an analytical tool or lens to explain the possible tensions between the current offerings in TVET Technical Engineering versus the advancing 4IR technologies.

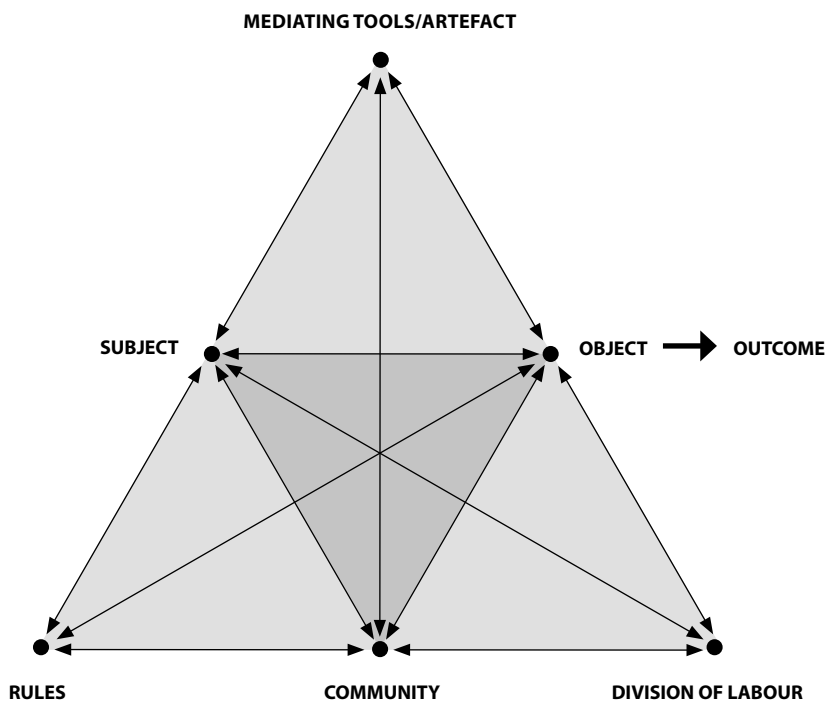


Figure 1: Engeström's (1999; 2001; 2007) 3rd generation Cultural-Historical Activity Theory (CHAT)

Figure 1 illustrates visually Engeström's (1999; 2001; 2007) CHAT model, which consists of various component nodes: subject, object, community, mediating tools/artefacts, rules and division of labour. The activity system dynamics of lecturers in Technical Engineering TVET pedagogical practices are illustrated in Figure 2.

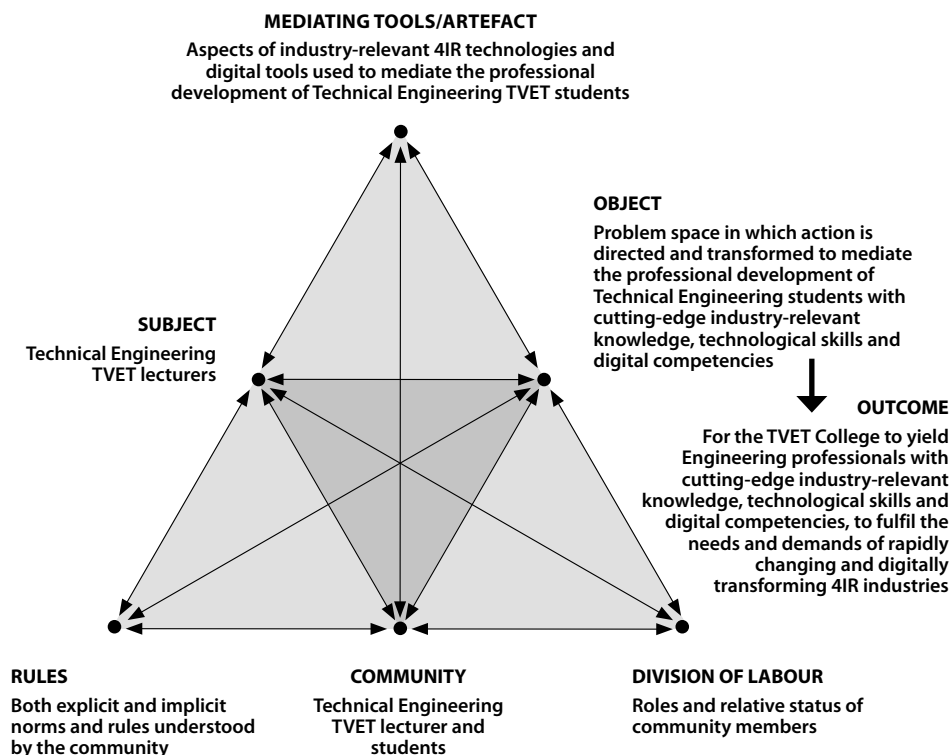


Figure 2: Activity system dynamics of lecturers in Technical Engineering pedagogical practices

An activity is embedded in a surrounding system: for example, the integration and use of industry-relevant technologies are embedded in the activity system of lecturers in Technical Engineering as they integrate technology in the pedagogy that plays out in the classroom. This, in turn, is embedded in the activity system of the TVET college as a whole. Within these embedded systems, the cultural life of the TVET college (or other settings) is developed and maintained. According to Leont'ev (1978; 1981), the central focus of the community's activities within an activity system is to achieve the object effectively using various kinds of mediating tools and artefacts – for example, emerging and advancing 4IR technologies and digital applications that are relevant to industry. It is important to recognise and define clearly the object of an activity system; however, it is not necessarily always required for all participants in an activity system to be fully aware of the object. For example, it is not necessary for students in a Technical Engineering classroom community always to be aware of the object of their lecturers' pedagogical practices. However, it is important for the subject (i.e. the lecturer) to identify the object clearly and to define it (i.e. the professional development of students with innovative industry-relevant 4IR technological and digital competencies). According to the identified and defined object, all the pedagogical activities in the activity system are directed towards attaining 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 – the capacity to interpret and expand the definition of the activity's object and to respond to it in increasingly enriched ways. In this regard, Daniels (2004:190) maintains that 'objects should not be confused with goals. Goals are primarily conscious, relatively short-lived and finite aims of individual actions'.

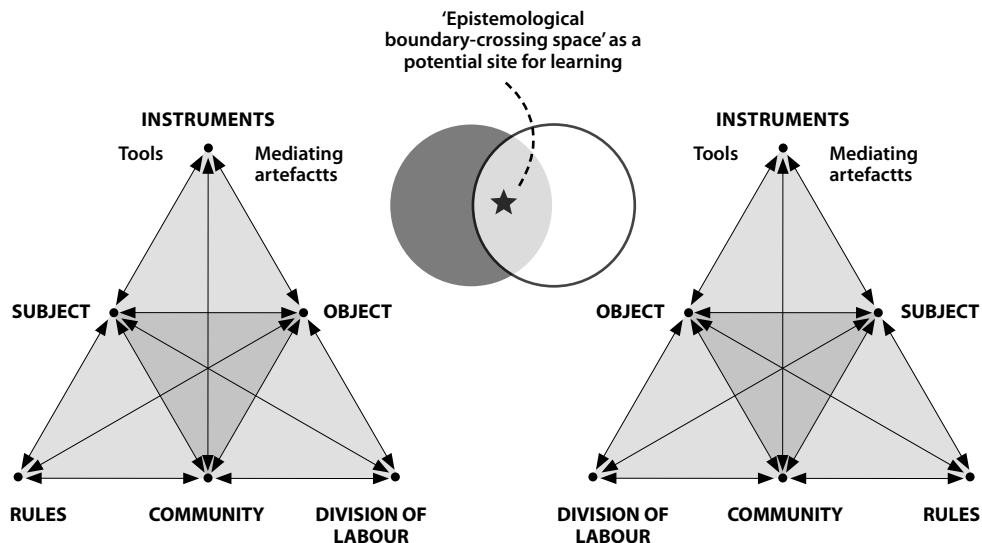


Figure 3: Epistemological boundary-crossing space between activity systems is a potential site for learning (own elaboration)

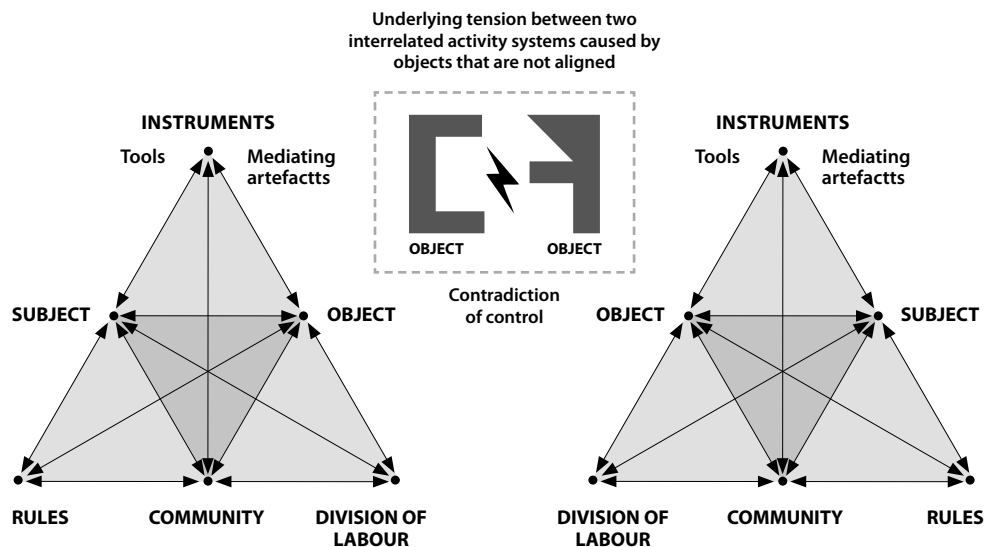


Figure 4: Underlying tension builds up between two juxtaposed activity systems when their objects are not aligned, causing a contradiction of control (own elaboration)

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 lecturer and a student share the same objective – it creates an epistemological boundary-crossing space as a potential site for learning (see Figure 3). However, when the objects of two interdependent activity systems are not aligned, it creates underlying tensions and conflict owing to a *contradiction of control* (see Figure 4). Such tension might hinder lecturers in Technical Engineering in integrating 4IR technologies successfully in their pedagogical practices.

Researchers and lecturers can use CHAT to explore and evaluate the inner dynamics of various activities and processes within the activity system of lecturers' pedagogical practices, mediated through industry-relevant technologies and technological applications. What is not clear is whether lecturers in Technical Engineering are responding effectively to the exponential digital transformation of industries brought about by 4IR by continuously upskilling their technological skills and digital competencies. Therefore, this article reports on the empirical findings of a national survey that collected data from lecturers in Technical Engineering at 52 TVET college campuses across South Africa (n = 577) that offer TVET Engineering Study programmes. The purpose of the survey was to profile the lecturers' knowledge and pedagogical practices in Engineering programmes across South Africa. The findings reported on in this article have been derived from a sub-section of the survey that specifically probed participants' awareness and understanding of discipline-specific technological advancements and digital educational enterprises, and also the potential impact of these on teaching technical subjects.

Research design and methodology

Profiling lecturers in Technical Engineering across the South African TVET landscape

This article reports on 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 lecturers in Technical Engineering at TVET colleges across South Africa's TVET landscape. The survey instrument collected the following categories of information from the participants in order to derive a comprehensive demographical profile of these lecturers empirically:

- demographic information (e.g. gender, age group, programmes, employment status);
- teaching qualifications and subjects taught;
- teaching and industry-based work experience;
- work-integrated learning (i.e. industry-based and school-based);
- professional development; and
- awareness, knowledge and competencies in the practical use and/or application of industry-relevant technological advancements in their fields of specialisation.

Selected empirical findings from only the first and last of these information categories are reported on in this article.

Research design and method of data collection

A descriptive cross-sectional research design was used for this quantitative investigation and the data were collected over a period of 26 months (July 2017–August 2019) from a random sample of lecturers (n = 577) in Technical Engineering on 52 campuses of 24 TVET colleges across all nine provinces of South Africa. A quantitative method of data collection was used, that is, a structured survey instrument. Cross-sectional research determines the ‘characteristics in a population at a certain point in time’ (Cherry & Gans, 2019:np), ‘with a defined start and stopping point’ (Fleetwood, 2020:np). It allows researchers to amass a great deal of information from a large sample of participants, for example, by means of a survey. Accordingly, a descriptive cross-sectional research design was followed to respond effectively to the DHET’s mandate to determine a recent national profile of lecturers in Technical Engineering across the country’s TVET colleges.

Development of the survey instrument

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

- existing educational policies and policy frameworks;
- the available corpus of knowledge pertaining to TVET research in South Africa;
- discourses on TVET professional development; and
- research team members’ participation in prior provisional development research projects.

Ethical considerations

Ethical clearance was obtained from both the UFS Research Unit (UFS-HSD2017/1487) and the DHET. Research applications were submitted to the principals of TVET college campuses and formal permissions were obtained from these colleges to administer the survey on their campuses. An informed consent letter was sent out to lecturers in Technical Engineering at all TVET college campuses. Participation in the survey study was anonymous and voluntary. The participants were treated with respect and were informed about their right to withdraw from the research process at any time or stage.

Data collection

The research team engaged with regional TVET college management and lecturers in Technical Engineering in order to contextualise and plan the data-collection process – access, availability and participation – to ensure that both the data would be collected according to

high ethical standards and that data collection would not interfere with or disrupt the normal academic activities at the 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 to administer the survey on the various TVET campuses to the 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 the lecturers were captured digitally in a combined quantitative dataset and were 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 purposes of the current discussion, only the descriptive statistical findings are reported on in this article.

Demographic information of the sample

In total, 850 surveys were distributed to lecturers in Technical Engineering on 52 campuses at 24 TVET colleges across all nine provinces of South Africa. A random sample of lecturers (n = 577) completed the survey instrument successfully, signifying a survey return rate of 67,88%.

Provincial distribution

The province most represented in the total sample (n = 577) of the participating lecturers in Technical Engineering was the Western Cape (n = 105 participants, i.e. 18,2% of the total sample); the province least represented was the Northern Cape (n = 42 participants, i.e. 7,3% of the total sample).

College distribution

Among the TVET colleges (n = 24) that participated in the survey, the TVET college in KwaZulu-Natal is the most represented by participants (n = 85, 14,7% of the total sample), whereas the TVET college in the North West province is the least represented (n = 5 participants, i.e. 0,9% of the total sample).

Gender distribution

The gender distribution of the total sample (n = 577) is 74,7% (n = 431) males and 23,7% (n = 137) females, which are similar to the gender distribution percentages reported by merSETA (2019:25) for the manufacturing sectors: 76% male and 24% female. It is evident from the clear similarity of the 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 reflect adequately the larger South African population of TVET lecturers within the Engineering disciplines. It remains unclear why 1,6% (n = 9) of the total sample decided not to indicate their gender group. Gender identity and the gender-related issues of lecturers in Technical Engineering for the most part remain unexplored and require the attention of future research.

Age distribution

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 36–40 years of age (n = 103; 17,9% of the total sample). The age group least represented in the total sample are those lecturers who fall within the age range 25 years or younger (n = 10; 1,7%). Again, one could merely speculate about possible reasons why 2,8% (n = 16) of the total sample did not report their age group.

Distribution of teaching programmes

When the participants were asked to indicate the programmes they teach:

- 47,5% (n = 274) indicated the NATED as their first teaching programme;
- 35,5% (n = 205) indicated the NC(V); and
- 17% (n = 98) did not disclose their first teaching programme.

Furthermore, 13,5% (n = 78) indicated NATED and 17,9% (n = 103) Skills, as their second teaching programme, whereas 68,6% (n = 396) did not indicate a second programme, as most lecturers teach in only one of the three TVET programmes.

Digital skills training

As previously mentioned, the DHESI, supported by CISCO Systems, Inc., developed digital skills training, which has been integrated into the NC(V) programme (Nzimande, 2021). Approximately 36% (n = 205) of the total sample of participants indicated that they received digital skills training which has been integrated into the NC(V) programme. These exposures could support the department's introduction of new Robotics streams into the NC(V) programme in 2022 (Nzimande, 2021). Minister Nzimande (2021) 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.

Empirical findings

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

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

One of the survey items requested lecturers in Technical Engineering to indicate specifically whether they are aware of any technological developments or advancements in their areas of specialisation.

Table 2: Participants' self-rated awareness of 4IR technological developments or advancements in their areas of specialisation

AWARENESS OF TECHNOLOGICAL DEVELOPMENTS/ ADVANCEMENTS IN THEIR AREA OF SPECIALISATION	FREQUENCIES (N)	FREQUENCIES (%)
Unaware of any technological developments/ advancements in their area of specialisation	302	52,3
Aware of any 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 or advancements in their areas of specialisation and 52,3% (n = 302) indicated that they were unaware of any technological developments or advancements (see frequency Table 2). Awareness could contribute towards their professional development of the technological literacy and digital competencies that are required for 21st-century technology-integrated learning environments that are industry-relevant.

The next survey item requested the participants to *Please specify any three of these technological developments in your area of specialisation that you are aware of*. Table 3 shows randomly selected examples (n = 76) of some of the technological developments that lecturers in Technical Engineering specified as 4IR technologies in their areas of specialisation in response to the survey item. Correctly specified 4IR technological developments are shaded in Table 3.

Table 3: Random examples of some of the 4IR technological developments in their areas of specialisation that lecturers in Technical Engineering specified

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

Assessors	Isolators
Auto-electrical qualification (Trade test)	Joint and termination
AUTOCAD Software integration and training	Knowledge of other languages (e.g. Mandarin) used in equipment
Automation, mechatronics, robotics, diagnostics, troubleshooting	LED lighting systems
Blended learning	Linux operation systems
Boilermaker specialist	Machining, phoning and videos
Brakes, brakes by wire, braking systems	Mechatronics (Automation)
Change of 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	Schematic hydraulic 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 development
Electrical and diagnostic advancement software	Surveyor land total station
Electricity	Test equipment – oscilloscope

Emission control systems	Toilet that uses sense devices
Energy recovery braking systems	Twizza soft drinks
Fibre concrete	Unit standards need to be revisited for the sake of relevancy
Film and media studies	Water-based paints
Geysers	Woodwork –kitchen installations

Although 37,6% (n = 217) of the total sample of participants indicated that they were aware of technological developments or advancements in their areas of specialisation (see Table 2), when asked to provide actual examples of such technologies, only 17,12% of the examples that participants provided in Table 4 were real examples of industry-relevant 4IR technological developments or advancements. It therefore seems as if the participants overrated their actual awareness of the technological developments or advancements in their areas of specialisation by 20%.

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

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

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

SELF-RATED KNOWLEDGE ABOUT THE PRACTICAL USE AND/OR APPLICATION OF 4IR TECHNOLOGIES	FREQUENCIES (n)	FREQUENCIES (%)
Not at all knowledgeable	22	3,8
Not so knowledgeable	36	6,2
Somewhat knowledgeable	99	17,5
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 or practical use and/or application of the technological developments or advancements, 4,2% (n = 24) rated themselves to be extremely knowledgeable, whereas 17,2% (n = 99) consider themselves to be somewhat knowledgeable (see frequency Table 4). Only 3,8% (n = 22) indicated that they do not have any knowledge about the actual or practical use and/or application of such technological developments or advancements,

whereas 6,2% (n = 36) consider themselves not so knowledgeable. Of the total group of participants, however, 50% (n = 289) 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 or advancements in their areas of specialisation

Table 5: Participants' self-rated competence in the practical use and/or application of the technological developments or advancements

SELF-RATED COMPETENCE IN THE PRACTICAL USE AND/OR APPLICATION OF 4IR TECHNOLOGIES	FREQUENCIES (n)	FREQUENCIES (%)
Not at all competent	20	3,4
Not so competent	39	6,8
Somewhat competent	99	15,1
Very competent	107	18,5
Extremely competent	26	4,2
Did not indicate	279	48,4
Total sample n =	577	100,0

Concerning the participants' self-rating of their own competence in the actual or practical use and/or application of these technological developments or advancements (see frequency Table 5), 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 or practical use and/or application of these technological developments or advancements. One could only speculate on a possible reason why 48,4% (n = 279) of the total number of participants (n = 577) 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 the participants were able to provide examples of actual 4IR technologies in their fields of specialisation (see Table 3), the data seem to lean more in favour of surmising that such non-responses could indicate those participants' incompetence in the practical use or application of 4IR technological developments or advancements.

Conclusion and recommendations

This study supported the DHESI's current reconstruction of Engineering programmes offered at TVET colleges in order to align them with and make them responsive to the rapidly changing needs of industries. The exponential digital transformation and automation of industries brought about by the 4IR is increasingly raising the complexity of knowledge

and skills required for entry-level positions in industries. Consequently, lecturers in Technical Engineering are mandated to continually improve or update their knowledge and skills in the practical application of the latest industry-relevant 4IR technological advancements in their areas of specialisation; they are also required to integrate the technological advancements effectively into their pedagogical practices. These lecturers should become experts in their fields of specialisation in order to mediate their students effectively so as to develop, not only theoretical knowledge, but also the applicable digital skills and hands-on technological capabilities that industries will demand of them in entry-level positions.

In order to accomplish this, lecturers in Technical Engineering must shift their pedagogical approach from a transmission-based 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 relevant to industry. Accordingly, this article provides guidelines for these lecturers on how to integrate industry-relevant technologies and digital competencies into their pedagogical practices progressively in order to achieve 21st-century learning outcomes. This article also shows how lecturers in Technical Engineering can progressively mediate the development of higher-order thinking skills and digital expertise in their Engineering students, relative to their respective levels of technology integration.

The DHET commenced the reconstruction of the curriculum for Engineering programmes in August 2020, a process that it is anticipated will be completed by June 2021 (Nzimande, 2021). As the fields of Electrical, Mechanical and Civil Engineering are being prioritised, the current curriculum reconstruction of Engineering programmes will directly affect 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 seem reluctant to capitalise fully 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 article show that, at the time of their participation in the national survey, 52,3% (n = 302) of the lecturers (n = 577) in Technical Engineering were unaware of any technological advancements in 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), some of the lecturers in the current investigation have received digital skills training, which has been integrated into the NCV programme (Nzimande, 2021). The findings reported in this article that relate to the lecturers' awareness of, knowledge of and competence in the practical use and/or application of industry-relevant 4IR technological developments or advancements offer a valuable point of reference for the DHESI against which to compare the effectiveness or success of the digital skills training that was implemented after August 2019 for lecturers in Technical Engineering in the NCV programme.

For their part, TVET colleges will have to invest in establishing the necessary infrastructure that is required for these lecturers to integrate industry-relevant 4IR technologies successfully into their pedagogical practices in technology-integrated learning environments. This will require them not only to invest in technology hardware and software, but also to provide applicable training opportunities for information technology (IT) staff and lecturers. Such training opportunities should enable them 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 the lecturers share the same objective: the professional development of students of Technical Engineering so as to give them cutting-edge industry-relevant 4IR technological and digital competencies. Doing so should avert any underlying tensions between the two activity systems that could result from a contradiction of control.

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