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South African Computer Journal

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Authors should submit papers for publication at the web site at http://www.sacj.org.za/index.php/sacj/about/submissions. Please also check there for the latest version of the below guidelines.

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SACJ is produced using the LaTeX document preparation system and we recommend using the Overleaf system. A *SACJ* template is available on Overleaf: https://www.overleaf.com/latex/templates/south-african-computer-journal/smnhsnmsnfdy. Though we can also accept Microsoft Word submissions, delays in publication are more likely with the latter format. While we encourage submission in a format similar to the published paper, authors should not waste undue time on layout as this will be redone by the production editor.

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Authors of conference papers are welcome to submit extended papers to *SACJ* for consideration on these terms:

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- the paper includes at least 30% new material

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- evidence is provided that republication in this form does not violate copyright of the conference publication

Book Reviews, Letters and Communications

Book reviews are welcome, as are letters to the editor; both should carry the author's full name and affiliation, and should be limited to 500 words. Communications and Viewpoints up to two pages in length (or longer, by negotiation with the editor-in-chief) may also reflect minor research contributions, works-in-progress or ideas to stimulate debate.

This category of submission is accepted at the discretion of the editor-in-chief, not refereed and does not qualify as a research publication for South African government subsidy purposes. The major criteria for acceptance are that the item is coherently written and does not require significant editing, that it is timely and it is likely to be of interest to readers.

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CONTENTS (CONTINUED)

Special issue (Part B): Reviewed papers

Editorial: Research beyond our borders

Katherine M. Malan – sacj.editor@gmail.com
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Contributions from Namibia and Ukraine

This first issue of SACJ in 2023 includes three papers from researchers outside South Africa: one from our neighbours in Namibia and two from Ukraine. The first paper from Namibia by Shapopi, Limbo and Backes describes the operation and running of Namibia's first high performance computer, how this experience has developed human capacity, and how the service is supporting scientific research. The paper is published in the form of a 'Communication', rather than a research paper. Communications in SACJ are publications of ideas or experiences that are deemed by the editor-in-chief to be of interest to readers. Although contributions of this category are not peer reviewed and hence would not qualify for government subsidy in the South African context, they still follow the usual copy-editing and production editing processes and are allocated a unique persistent DOI like regular research papers.

Similar to Communications, Viewpoints are publications of research-in-progress that are not peer reviewed. In this issue, we have two articles published as Viewpoints from the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine. Since Russia's invasion of Ukraine in 2022, the work of Ukrainian researchers has become very challenging due to the large-scale decrease in funding for research projects. In addition, many researchers were mobilised into the ranks of the armed forces and those who are keeping research going in cities such as Kyiv have to contend with the unpredictability and destruction of ongoing rocket attacks. We are therefore happy to support these researchers in a small way by disseminating their work. Figure 1 provides a glimpse into the research lab in Kyiv of the authors who contributed to this issue.

Both articles from Ukraine are related to ontologies. The first paper by Malakhov, Petrenko and Cohn describes the architectural and structural organisation of an ontology-related system for processing repositories of scientific publications. The second paper by Litvin, Palagin, Kaverinsky and Malakhov describes an approach for the automated creation of ontologies from natural language text and provides a software implementation parameterised for the Ukrainian language. We hope these articles will be of interest to researchers in South Africa

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Figure 1: Kyrylo Malakhov being interviewed by local media about the work of their research team with the Kyiv territorial defence squad *(photo courtesy of Kyrylo Malakhov)*.

that are active in the field of knowledge representation and reasoning, such as those associated with CAIR (Centre for Artificial Intelligence Research).

Other contributions in this issue

Other than the Communication and Viewpoints, this issue also consists of an obituary and eight reviewed research papers. The obituary, written by Estelle Trengove from Wits, celebrates the life of Prof Barry Dwolatzky. His passing is a great loss to many in our community, but he will be fondly remembered for his passion for software engineering and for the many positive initiatives that he instituted to develop the South African ICT sector.

The first reviewed research paper in this issue is by de Coning, Hoffman, and Mouton titled *"Traffic control centre optimisation on South African freight corridors through intelligent weigh-in-motion"*. The study is concerned with efficient detection of overloaded freight trucks on our highways. Currently, too many trucks are incorrectly flagged as overloaded (based on weigh-in-motion estimates) and are diverted to static weighing stations, resulting in unnecessary and costly delays. The authors propose a solution that includes data sharing between control centres and AI-based classification, and show that this approach would result in a significant reduction in unnecessary diversions to static scales.

The rest of this issue consists of papers for the special issue on *Digital education and online learning to achieve inclusivity and instructional equity* with guest editors Reuben Dlamini and Rekai Zenda. The first part of this special issue was published in the December issue of 2022 and in this issue, we include the remaining papers, which are discussed in detail in the Guest Editorial.

New URL and platform

We are pleased to announce that SACJ has a new URL (https://www.sacj.org.za/), which for the mean time has been set up to point to the current site (http://sacj.cs.uct.ac.za) hosted by UCT's Department of Computer Science. During the second half of 2023, we will be moving

SACJ to a new platform hosted by the Academy of Science of South Africa (ASSAf), as part of Khulisa Journals (https://journals.assaf.org.za/). The advantage of moving to the Khulisa Journals Platform is that they will take care of the maintenance and updating of the OJS software and we can also benefit from their expertise in terms of best practice for open access journal management.

Guest editorial: Digital education and online learning to achieve inclusivity and instructional equity (Part B)

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This special edition has been published at a time when the Fourth Industrial Revolution (4IR) and the outbreak of the COVID-19 pandemic have added to the fast-tracking of education and research (Alnagrat et al., 2022), and when higher education institutions (HEIs) are faced with the demands to transform into technological hubs and be 4IR savvy (Telukdarie & Munsamy, 2019). In response to strict COVID-19 regulations, universities cancelled all face-to-face classes and transitioned to digital education and online learning or emergency remote teaching (ERT) (Hodges et al., 2020). Bagarukayo and Kalema (2015) reported that HEIs and schools have adopted technology solutions to support their daily operations, not only in teaching and learning but also in support services.

Moreover, the need to enhance teaching and learning efficiency has led to the emergence and adoption of different technological innovations. Central to the transition were digital learning platforms known as learning management systems (LMS) to enable online teaching and learning. Linder et al. (2017, p. 27) define LMS as "a software system that offers an organisational structure for a range of course tools to be used by both groups and individuals online". These digital platforms enable online delivery of lectures and study materials (Adikwu et al., 2017) and facilitate communication between teachers and students (Naik et al., 2020). A study conducted by Makumane (2021) revealed that students viewed LMSs as promoting professional identity (performance curriculum) as they get easy access to content uploaded by lecturers. In this regard, technology's interactive and dynamic offerings have changed the face of teaching and learning (Faloye et al., 2020).

Papers in this special issue herald the positive side of the digitisation of student learning. The primary function of technology integration in education institutions is its capacity for interactive learning through discussion, sharing and delivery of module materials, communication and multimedia. With so much exposure to the technology, teachers hardly have

Dlamini, R., Rekai, Z. (2023). Guest editorial: Digital education and online learning to achieve inclusivity and instructional equity (Part B) [Guest Editorial]. *South African Computer Journal* 35(1), ix–xiv. https://doi.org/10.18489/sacj.v35i1.1260

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a choice other than to embrace the new technology and facilitate interactive teaching and learning to students. The use of digital technologies not only influences teachers' pedagogical approaches, but also has a positive impact on the achievement of learning outcomes (Chandra & Mills, 2014).

This special edition aims to set an agenda for research, the operationalisation of digital education and the positioning of digital technologies to create inclusive learning environments. The White Paper on e-Education (Department of Education, 2004) states that ICT offers greater opportunities to access learning, redress inequalities and improve the quality of teaching and learning. In this regard, the digital transformation of education involves a shift from traditional pedagogy to more learner-centred, technology-driven learning with enhanced teaching and learning experiences (Ankiewicz, 2021; Osmundsen et al., 2018). observed that technology enables teachers to cater to students' diverse needs. If learners receive quality education, they reduce inequalities and achieve gender quality to create an inclusive society.

However, there is a legitimate concern about the isolating nature of digital education and online learning. While the transition to digital education and online learning has been lauded as efficient, flexible and encouraging higher engagement with course material, the biggest challenge is the absence of research informing the transition and instructional design principles informing the design and development of the online courses. Dlamini (2018) argued that any reactive and simplistic approach concerning the implementation of digital education, online learning and digital learning platforms as well as technologies in universities has the potential to promote ideals of classism. In fact, there is lack of empirical work to ground the discourse, especially in resource constrained contexts. Thus, unequal access to digital resources has aggravated digital inequalities and inequity. Mhlongo and Dlamini (2022, p. 1) asserted that "approaching digital technologies from a utility perspective places these tools at crossroads with broader social and contextual issues". Unequal access to digital resources and competencies has the potential to widen the access gap to education. In our experience, it has become clear that the discourse on 'Digital Education & Online Learning to Achieve Inclusivity and Instructional Equity' has not been adequately debated and researched scientifically in the South African context.

As such, there has been a great need for high-quality papers that reflect various perspectives on 'Digital Education & Online Learning' especially with accelerated transition towards digital education and online learning in the education sector. The papers in this special issue explore the interplay between digital affordances and cognitive dimensions as well as the theoretical and epistemological literature on adopting and appropriating technology in education. Further, this issue provided an opportunity for researchers to share best practices, contribute contextual knowledge, bring about diverse perspectives on how the interplay between technology and education is perceived and how changing discourses impacts teaching and learning practices. The papers in this special issue discuss and provide critical reflection on various digital technologies and their impact on pedagogical practices and also how they act as catalysts for change in the education sector. It brings together distributed research to inform teaching and learning using various technological innovations and digital pedagogies.

In this special issue, Chomunorwa, Mashonganyika, and Marevesa explored "*Digital transformation and post-Covid-19 education in South Africa: a review of literature*." A systematic literature review was used as the methodology for this study that included keywords such as digital divide, education, digital transformation, inclusive education, and post-Covid-19 education. The study highlighted the challenges to address past inequalities, including lack of resources, language barriers, technological shortcomings and skills and knowledge shortage. Chomunorwa, Mashonganyika, and Marevesa recommend the development of student basic practical skills to enhance lifelong learning, satisfaction, happiness, well-being, opportunity and contribution to humanity. It is imperative that the curriculum focuses on teaching students' creativity, entrepreneurial thinking and competency to succeed in the age of smart machines and globalisation.

Faloye and Faniran reported on "*Integrating technology in teaching and learning practices: Students' competencies*." The study investigated student competency levels based on factors such as their prior exposure to computers and the availability of facilitating conditions such as human or technical support. According to Faloye and Faniran students who had access to a computer prior to entering university are likely to be more competent in their usage than those who had access after joining the university. The findings showed that the provisioning of facilitating conditions in a technology-integrated academic environment positively influences student competency in the use of technology.

Ngqulu and Nomnga in the article entitled, "*Covid-19 pandemic: A necessary catalyst for e-learning adoption and application*" assess the state of e-learning before and after the first six weeks of lockdown regulations in two higher education institutions (HEIs), using a theoretical framework of e-learning system readiness assessment and a participatory research approach. The findings reveal a state of under-preparedness by HEIs to operate under the lockdown regulations, due to the adopted blended learning policy implementation gap. However, the study concludes with an argument that the Covid-19 pandemic presented a great opportunity for HEIs not only to adopt e-learning at the policy level but also to adapt to the new e-learning methods and practices and thus prepare universities for times of uncertainty.

Molotsi, Moodley and van Wyk explored the "*Grade 9 teachers' experience of digital technologies in the classroom*." The study was framed by the Technological Pedagogical and Content Knowledge (TPACK) framework. The findings revealed limited integration of digital technologies in delivering lessons making technological lnowledge (TK) non-existent. This is a result of not having the technology available, lack of support, and of not having the knowledge or "know how" to integrate digital technologies. In their study the value of supportive school leadership and the need for continuous professional development opportunities is evident. The study recommends that more research is conducted regarding the lack of pedagogical knowledge and strategies planned to provide training opportunities for teachers on the integration of both technology and pedagogy knowledge to deliver their lessons.

Gumbo reported on "*Digitisation of higher education and research: Raising inclusivity and equity issues for indigenous students*". The conceptual study critiques digitisation of higher education and research as it relates to inclusivity and equity for indigenous students. The article

contributes insights into the vulnerability of indigenous students and argues that institutions for higher learning are uncritical of the digitisation of their learning, knowledge and research. Gumbo's conceptual paper conscientises higher institutions of learning to digitise learning and research from a transformational perspective.

Zuma and Mthembu, in their article "*Exploring ideological-ware as a resource in the use of Moodle in higher education - analysing Covid-19 publications*" reported on the use of digital technology such as Moodle in higher education institutions that demonstrate shared-, self- and specialised-experiences. They emphasised the essence of ideological-ware in blended learning. Thus, lecturers need to have teaching strategies and creative ways when using hard-ware and soft-ware for teaching, and to consider students when thinking about ideas and teaching theories that will fit for each topic and the resources available.

Shandu-Omukunyi investigates the learning and teaching of English First Additional Language (EFAL) using digital resources, through the work entitled "*English First Additional Language learning and teaching with digital resources*". The aim was to understand whether the pedagogical digital literacy practices and the use of digital resources enhance the learning of EFAL. Through the lens of Computer Assisted Language Learning (CALL) theory and Technological Pedagogical Content Knowledge (TPACK), the study argues that the integration of technology helps teachers to deliver the EFAL content in a flexible and enhanced way. The amalgamation of an e-education policy with the Language in Education Policy (LiEP) and the Curriculum Assessment Policy Statement (CAPS) for the implementation of language digital teaching practices in basic and higher education should be explored. Further, the findings reveal that teachers require being equipped with digital literacy skills to effectively teach the languages.

This special edition focuses on research that helps us to understand how digital education and online learning widen access to education. We are of the view that digital tools open up exciting and innovative instructional avenues that may be used to overcome student passiveness, time and enhance inclusive pedagogies. We therefore invited the submission of papers for this special issue to gather a collection of high-quality papers that reflected various perspectives on digitalisation and online learning.

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Obituary - Prof Barry Dwolatzky

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Prof Barry Dwolatzky was very proud of the name *Grand Geek* given to him by some former students, but he was much more than a computer geek. He was a leader and a visionary in the field of software engineering in South Africa.

An alumnus of the School of Electrical and Information Engineering at the University of the Witwatersrand, Barry graduated with a BSc Eng (Elec) in 1975. He started with an MSc Eng, which he converted to a PhD.

After obtaining his PhD in 1979, he did post-doctoral research at the University of Manchester's Institute of Science and Technology and at Imperial College in London. Thereafter, he worked as a senior research associate at the GEC-Marconi Centre in the UK.

He returned to South Africa in 1989 as a senior lecturer in the School of Electrical Engineering at Wits University, teaching the Microprocessors course. When he joined the School, there was only one programming course, Engineering Applied Computing, that was taught to second-year electrical, civil and mechanical engineering students. Barry was instrumental in moving away from Pascal, a programming language based on functional decomposition, to C++, an object-oriented programming language. Object-oriented programming is now widely accepted as the better paradigm, but at the time it was a bold step. In the software community around the world, it was hotly debated whether functional decomposition or object-oriented programming was better.

The School of Electrical & Information Engineering's curriculum currently contains two second-year programming courses and a third-year course that is compulsory for all electrical and information engineering students. Barry was instrumental in introducing all these courses. This rigorous training in programming and IT has made the School's students attractive to the IT industry.

Talking to people in various companies, Barry realised that most of the School's graduates went into the ICT sector. He conceived of the idea of introducing a software stream that would be distinct from the electrical engineering stream. In 2000, the School's name was officially changed from School of Electrical Engineering to School of Electrical & Information Engineering. The first two years of study remained the same. In their third year, the information engineering students took courses in telecommunications and data management whereas the electrical engineering students took power and electromagnetic engineering courses. Final

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year information engineering students took a different set of elective courses.

One of Barry's other curriculum innovations was that he introduced a Sociology course called Engineer in Society. This course aligned the Wits electrical engineering program with the requirements of the Washington Accord. The Engineering Council of South Africa (ECSA) is a signatory of the Washington Accord. ECSA is responsible for accrediting engineering programs in South Africa. Being a signatory means that the degrees of graduates of accredited programs are recognised in all Washington Accord countries.

In the late 1980's, the then CEO of ESKOM, South Africa's national electricity utility, announced a mass roll-out of electrification called Electricity for all. Between 1990 and 2000, about 2.5-million houses were connected to the national grid. At that time, Barry started working on a software program that would assist engineers in planning the electrification of townships. A number of postgraduate students under his supervision worked on aspects of this software. He called the program CART (Computer-Aided Reticulation of Townships). In 1997, he took a year-long sabbatical and worked fulltime on CART, developing it into a viable commercial product that was used to aid in the design of the electrification of many townships.

In 2005, Barry launched the Joburg Center for Software Engineering (JCSE). The first director was Rex Van Olst, but in 2007, Barry took over as director. He ran the JCSE until he passed away. It was the work that he did through the JCSE that established him as an important thought leader in the software and IT space. He established a partnership with the Software Engineering Institute (SEI) of the Carnegie Mellon University in the United States. He introduced the SEI's Capability Maturity Model Integration (CMMI), a process improvement model for software development, in South Africa. He raised funding to train CMMI trainers and assessors in South Africa.

The JCSE hosted masterclasses with world renowned software experts, like Kent Beck, the father of Extreme Programming and test-driven development. He also brought one of the early proponents of object-oriented programming, Ivor Jacobsen, to South Africa.

In 2012, Barry identified some derelict buildings in Braamfontein that belonged to Wits University, as an ideal site for an innovation hub. Many people speak fondly of how Barry took them into a derelict disco with only the light from his mobile phone and enthusiastically explained how this was going to be a tech co-working space. He raised a phenomenal amount of funding and transformed the run-down buildings into the innovation hub that is today one of the flagship projects of Wits University. It is called the Tshimologong Digital Innovation Precinct. Tshimologong is the seTswana word for 'place of new beginnings.' Barry was the first director of Tshimologong and he was honoured for this visionary project with the Vice Chancellors Award for Research and Teaching in 2016.

Barry retired at the end of 2017 and was given the title Emeritus Professor, but he kept working as the director of the JCSE.

He was named the IIPITSA (Institute of IT Professionals of South Africa) joint IT Personality of the Year, sharing the award with the head of Microsoft South Africa Mteto Nyathi. In 2016 Barry received IITPSA's award for Distinguished Service to the IT Profession.

During the COVID lockdown in 2020, he started a podcast called *Optimizing – Leading*

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Africa's Digital Future and produced 8 episodes. He also wrote an autobiography called *Coded History – My life of new beginnings*, that was launched at Tshimologong in November 2022.

Over the last two years, Barry assisted the Wits Deputy Vice Chancellor, Prof Lynn Morris, to establish the Wits Innovation Center, which was launched on 17 April 2023. A week later, he was admitted to hospital, where he passed away on 25 April, with his wife Rina and his children Leslie and Jodie at his side.

Photo courtesy of the University of the Witwatersrand

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Communication

Namibia's first high performance computer

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SUMMARY

High performance computing (HPC) refers to the practice of aggregating computing power of several computing nodes in a way that delivers much higher performance than one could achieve by a typical desktop computer in order to solve large problems in business, science, or engineering. The University of Namibia has so far received two HPC racks from the Centre for High Performance Computing in South Africa, of which one is operational. The primary use of the rack was foreseen to be human capacity development and awareness in HPC and to form part of Namibia's readiness in participating in the Square Kilometre Array (SKA) and the African Very Long Baseline Interferometry Network (AVN) projects, but is now also being used for research in multi-wavelength astronomy and beyond. This is one of the first HPC services set up and operated by an entirely African team. We perform tests to benchmark the computational power and data transfer capabilities of the system and find that each node, on average, has a peak performance power of 82.4 ± 1.1 GFLOPS. *We also summarise all the projects that have enlisted the HPC facility.*

1 INTRODUCTION

Over the past two decades, the infrastructure and human capacity for high performance computing (HPC) has been steadily increasing in African countries. The Centre for High Performance Computing (CHPC) in South Africa has provided HPC facilities to researchers in Africa (Amolo, 2018). This was done in conjunction with the African School on Electronic Structure Methods and Applications (ASESMA), which is a biannual school to introduce researchers and graduate students to computational modelling (Chetty et al., 2010). A number of countries in Africa now use HPC facilities for weather and climate modelling and in most cases, this is done on the facilities provided by the CHPC (Bopape et al., 2019; Somses et al.,

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2020). The Southern African Development Community (SADC) Cyber-Infrastructure Framework, which aims to build capacity in regional research and education networks, data sharing infrastructure and trained human capital, has an infrastructure development pillar which has commissioned a few sites and deployed HPC systems (Bopape et al., 2019; Motshegwa et al., 2018). To date, most of the HPC systems that have been deployed, have also been used for weather modelling and considerations by a few countries have been taken to integrate high performance computing into university curricula (Mwasaga et al., 2015; Narasimhan & Motshegwa, 2018). The Abdus Salam International Centre for Theoretical Physics (ICTP) ran a 3-year project between 2008 to 2011 with the purpose of developing infrastructure and human capacity. Within this project one HPC system with 80 cores was donated to the Addis Ababa University in Ethiopia (Abiona et al., 2011).

With steady developments in astronomy in Africa (Pović et al., 2018) and Namibia (Backes et al., 2018) in 2016, the University of Namibia (UNAM) received one rack of computing nodes that was previously part of the Texas Advanced Computer Center (TACC; University of Texas, Austin) *Ranger* supercomputer, which had its debut in 2008 as the 5th most powerful computer in the world (Black, 2014; Erich et al., 2008b). The *Ranger* was re-purposed to function as single racks that were distributed to a select number of institutes in the African Square Kilometre Array (SKA) partner countries (Black, 2014), one of which is the University of Namibia. This was a result of the efforts made by the CHPC in South Africa and the Namibian National Commission on Research, Science, and Technology (NCRST), which facilitated the delivery. The CHPC coordinates the HPC Ecosystems Project (Johnston, 2019) which has the objective of facilitating readiness in advanced research computing for the upcoming Africa Very Long Baseline Interferometry Network (AVN) (Gaylard et al., 2011) and Square Kilometre Array (Carilli & Rawlings, 2004) projects. Since 2017, this single rack, together with a manager node has been operational as the first HPC system in Namibia, as the UNAM HPC (UHPC).

1.1 The UHPC/Head Node

The manager node of the cluster at UNAM is a Dell T430 server, running two central processing units (CPUs), specifically Intel Xeon E5-2603s. Each CPU has six cores with a peak frequency of 1.7 GHz. This server has 32 GB of random access memory (RAM) available, and has the capacity to accommodate 384 GB, leaving sufficient room for expansion. The server currently has 13 TB of storage installed, which is set up as central shared storage for the whole cluster. This node will serve as the manager node to the two entirely different computing racks and a storage rack, i.e. this node is to run a spectrum of discrete non-identical hardware.

1.2 The UHPC/Ranger

The rack of the former *Ranger* HPC hosts four shelves, each with 12 server modules ('nodes'), for a total of 48 server modules, as can be seen in Figure 1. It is a Sun Blade 6048 modular system and is designed so that it is easy to service (Sun Microsystems, Inc., 2009). Further

details about the dimensions can be found in the comprehensive site planning guide (Oracle and/or its affiliates, 2012). For this system, each compute node contains 4 AMD Opteron 8356

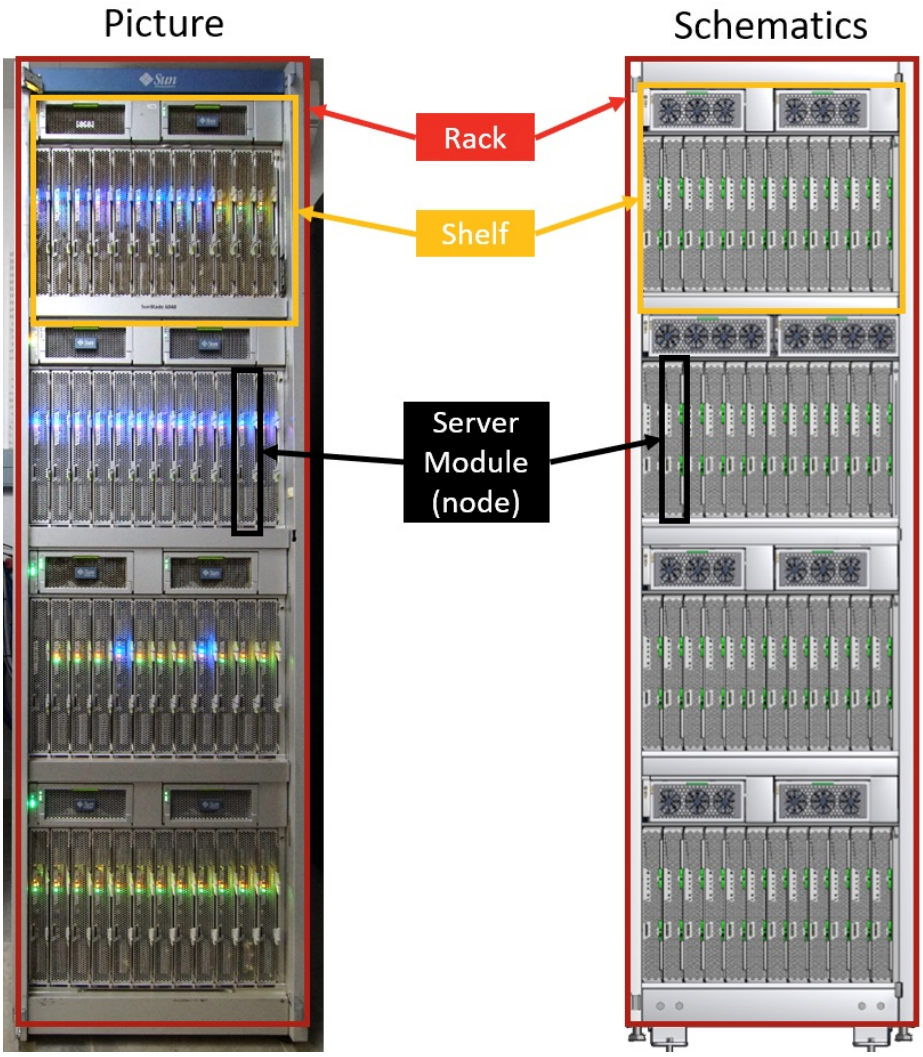

Figure 1: An image and schematic to illustrate naming conventions. On the left is an image of the *UHPC/Ranger* in operation and on the right a schematic from Sun Microsystems, Inc. (2009). The rack houses four shelves which, in turn, each house 12 server modules (nodes).

quad-core CPUs with a peak frequency of 2.0 GHz. Each core boasts 2 GB of RAM for an aggregate memory of 32 GB per node (Limbo et al., 2019). The peak performance of the *UHPC/Ranger* is calculated from the current peak performance power of each server module as shown in Equation 1.

$$\text{RPEAK} = \#\text{nodes} \times \frac{\#\text{cores}}{\text{node}} \times \frac{\text{cycles/second}}{\text{core}} \times \frac{\text{operations}}{\text{cycle}} \tag{1}$$

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RPEAK is the peak theoretical performance and the cycles/second is also known as the frequency of each core. Applying Equation 1 to the *UHPC/Ranger* using the details indicated in Table 1 yields, RPEAK = 6.1 TFLOPS[1]. A test of this performance is demonstrated in Section 2.4.

Table 1: Summary of performance values for the *UHPC/Ranger*.

#nodes	#cores/node	cycles/second/core	operations/cycle
48	16	2.0 GHz	4

2 OPERATION

This section outlines the current operational procedures used for the UHPC cluster. As of yet, 24 computing nodes are powered for sustainability of the HPC cluster and for maintenance, half of the 48 modules are kept as spares. Capacity building activities are ongoing as will be outlined in Section 2.7.

2.1 Setup

The setup and operational details of the UHPC can be seen in Figure 2. Users connect to the UHPC via a secured protocol, mostly Secure Shell (SSH), to the *UHPC/Head Node* passing through the university firewall. A 1 Gbit/s fibre link connects the firewall to the internet and the head node to the firewall. As outlined in Section 1.1, the *UHPC/Head Node* currently hosts 13 TB storage and will soon be bolstered by a storage server as indicated in the figure and outlined in Section 3.1. The *UHPC/Head Node* is connected to the computing nodes through a 48-port switch. The connection between the *UHPC/Head Node* and the switch is a 1 Gbit/s Ethernet link, as are the connections between the switch and each computing node.

2.2 Software stack

The UHPC cluster employs open source software for both server and computing nodes. The software being used is mainly from the OpenHPC stack, with CentOS as the base operating system for both the server and computing nodes and Portable Batch System (PBS) as the scheduling software (Johnston, 2019). The UHPC site was the first site in the entire SADC HPC Ecosystems Project to deploy the OpenHPC stack on the *UHPC/Ranger*, with CentOS version 7.6. The cluster uses the Ganglia software to monitor different load of the hardware such as CPU and RAM usage. Ganglia is a scalable distributed monitoring system for HPC systems such

[1] 1 TFLOPS = 10^{12} floating point operations per second (FLOPS)

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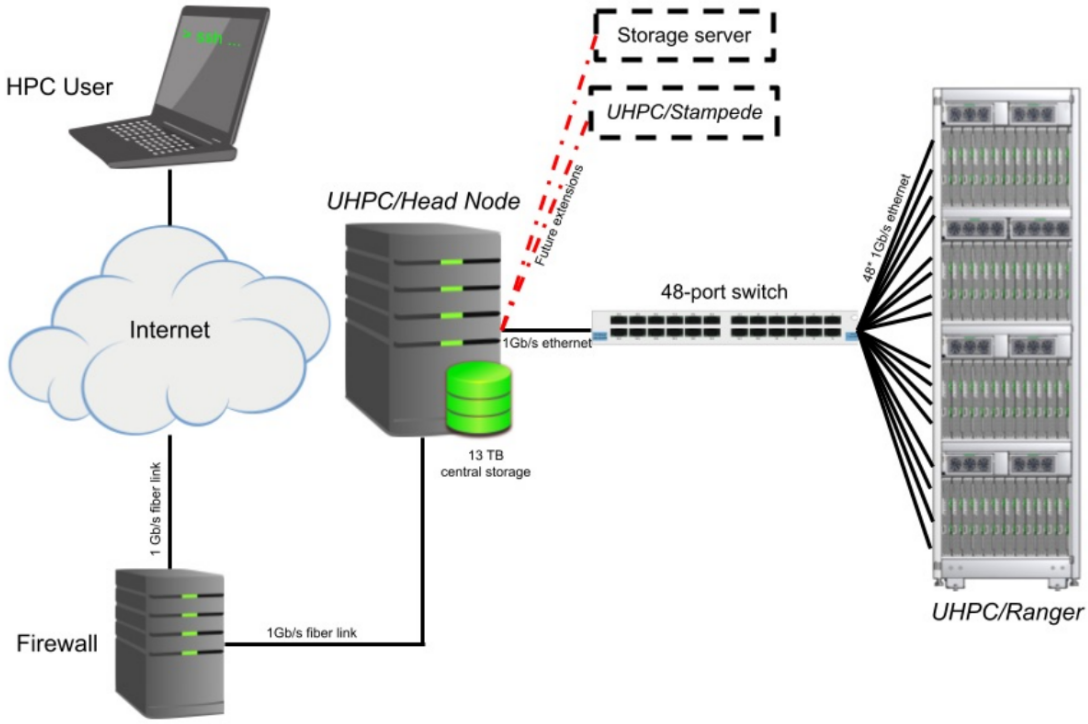

Figure 2: A schematic of the interconnection between different components of the UHPC and the outside world. Users connect via Secure Shell connections to the *UHPC/Head Node* after being authenticated by the university firewall and submit jobs via this *UHPC/Head Node* to the computing nodes on the *UHPC/Ranger*. The *UHPC/Ranger* is connected to the *UHPC/Head Node* via a 48-port switch and gigabit Ethernet. The red (dash-dotted) lines indicate the soon-to-be implemented expansions of the UHPC.

as clusters (Massie et al., 2004). It takes advantage of the a few widely used tools for data representation, compact data transport, storage and visualisation.

2.3 Using the cluster

Users access the cluster using Secure Shell. New users can request for a user account from the internal UHPC website[2]. The website also has guides for users to familiarise themselves with the cluster such as uploading and downloading data, submitting a job to the scheduler, monitoring a job submitted to the scheduler as well the results of a submitted job. For users that are not familiar with using a cluster, the Virtual Institute of Scientific Computing and Artificial Intelligence (VI-SCAI) offers regular workshops and training aimed at equipping users with the necessary skills to work with an HPC cluster. Usage of the cluster currently is free of charge, however, users are required to give acknowledgement to VI-SCAI in published articles that used the UHPC.

[2] uhpc.unam.na (Only accessible within the local UNAM network)

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2.4 Performance

The performance of an HPC cluster is influenced by a number of factors and the performance of any given processor may differ from instance to instance. The number of floating point operations per second (FLOPS) has long been a benchmark standard for estimating the computational power of an HPC system and the LINPACK Benchmark software is the most recognised approach for ranking HPC systems (J. Dongarra & Heroux, 2013; J. J. Dongarra et al., 2003). Stating FLOPS is rarely useful for comparing real world performance (Vetter et al., 2005), however, it does help to give an overview of a cluster's possible capabilities and is a quick way to quantify these capabilities. Additionally, the wide use of the test allows for easy comparability.

At its inauguration, the *Ranger* was ranked the fifth fastest supercomputer in the world, with a measured computational power peaking at RMAX = 326 TFLOPS while the theoretical RPEAK = 503.8 TFLOPS for the system of 3,936 nodes with 62,976 cores (Erich et al., 2008a, 2008b). This corresponds to an efficiency of 64.7%. It can be estimated that the power for each rack, i.e. 48 nodes, then was 3.9 TFLOPS and for each node 82.8 GFLOPS, accordingly. This calculation is a good estimate as the LINPACK Benchmark scales linearly with the number of CPU cores. It is noted that Erich et al. (2008a) states a different value for the theoretical computing power of the *Ranger* (RPEAK = 579.4 TFLOPS) than the one stated above. This stems from the fact that Erich et al. (2008a) also record a different value for the cycles per second: 2.3 GHz as opposed to 2.0 GHz. Here, we use the 2.0 GHz values as stated in Erich et al. (2008b), as this leads to consistently reproducing the cited results as described below.

We perform a LINPACK Benchmark for the currently active nodes of the *UHPC/Ranger* and receive an average of 82.4 ± 1.1 GFLOPS per node. Figure 3 shows the performance for each node in the *UHPC/Ranger* at the UHPC cluster. Theoretically, at 4 operations per cycle and a processor speed of 2.0 GHz (see Table 1), one would expect 128 GFLOPS of processing power. Thus, the *UHPC/Ranger* nodes are operating at 64.40 ± 0.88%-efficiency, on average, which is consistent with the 64.7%-efficiency stated in (Erich et al., 2008b). In total, with all nodes operating, the *UHPC/Ranger* is capable of 3.955 ± 0.052 TFLOPS, compared to the peak theoretical performance RPEAK = 6.1 TFLOPS, calculated in Section 1.2.

2.5 Data exchange capabilities

Data transfer is becoming a demanding area in the world of science. Large data transfers are common in the age of information. This work is done in an effort to understand how easily data can be transferred between the UHPC and other HPC systems regionally (in South Africa) and internationally (in Germany). This section presents the results of data transfers between the High Performance Computer at the University of Namibia, an HPC operated by the astronomy group of the School of Physics at the University of the Witwatersrand (Wits) in Johannesburg, South Africa, and an HPC at the Max-Planck-Institute for Nuclear Physics in Heidelberg (HD), Germany. These tests serve as a benchmark for further big data work, including large data transfers, to be conducted with the UHPC.

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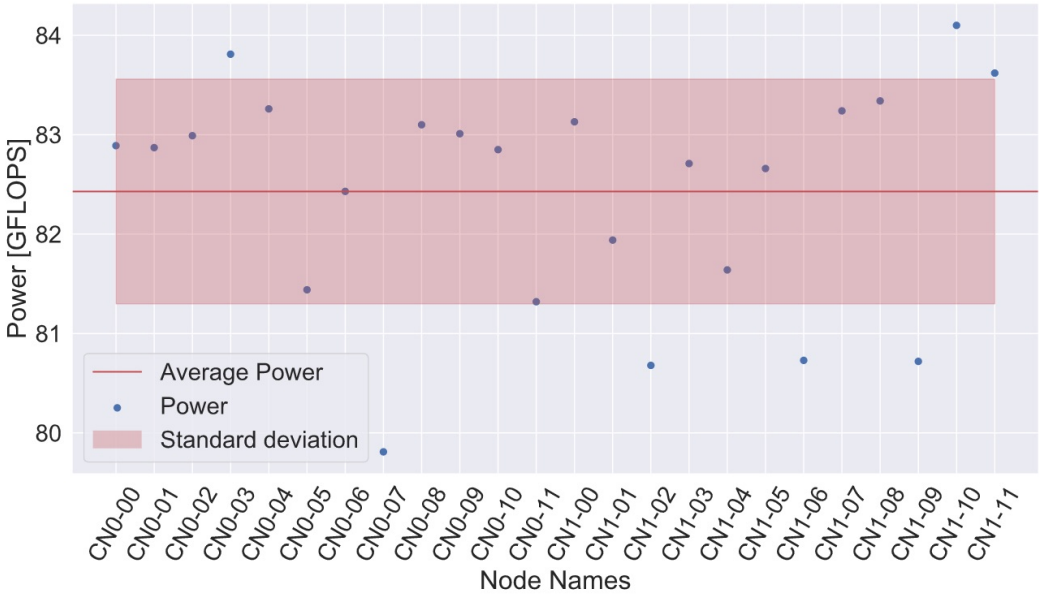

Figure 3: HPL LINPACK Benchmark results. The scatter plot shows the performance of 24 nodes of the UHPC cluster. All nodes are in the range of 79.8 – 84.1 GFLOPS with an average of 82.4 ± 1.1 GFLOPS.

For this, a 1 GB data set was prepared using C++: 1.25×10^8 random 64 bit floating point numbers were generated in an ASCII file, outlined in two columns. This file was exactly 1 GB in size and served as the test data set. This data was transferred to and from the clusters in Germany and South Africa using the `scp` command. The output of `scp` was written to a text file. Using `sed` the text file was reformatted and appended to a standard data file which had the modified Julian date (MJD) time taken for transfer and average transfer time. The transfer was repeated for a full week, every hour of every day.

Data transfers between HD and UNAM were conducted in the week of 19 February 2019 (MJD: 58533.441910) to 26 February 2019 (MJD: 58540.819460) and those between Wits and UNAM were performed in the week of 11 February 2019 (MJD: 58525.611143) to 18 February 2019 (58532.652806). Both pairs of transfers were done in both directions. Table 2 summarises the results obtained for these data transfers.

The upload and download speeds between UNAM and HD appear to be limited at about 10 MB/s, whereas the download speed from Wits to UNAM seems throttled at below 2 MB/s. The upload speed of the UNAM cluster appears limited only at a minimum of 50 MB/s. In Table 2, medians are reported as the distributions observed for the transfer times and speeds are skewed, often with distant outliers. Figure 4 show the distributions of the speeds and times of transfer. In these figures, it can be seen how the outliers affect the average values; the median seems a more appropriate qualifier.

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Table 2: Transfer summary of 1 GB data to and from HD and Wits with UNAM hosting the test cluster. The minimum and maximum values for the times of transfer and speeds of transfer are presented, along with their medians, averages and the standard deviation of the transfer speed.

	HD		Wits	
	to	**from**	**to**	**from**
Minimum Time (s)	112	115	22.0	648
Maximum Time (s)	279	690	453.0	909
Median Time (s)	140	172	42.0	684
Average Time (s)	**151**	**189**	**63.4**	**705**
Minimum Speed (MB/s)	3.9	1.6	2.4	1.20
Maximum Speed (MB/s)	9.8	9.5	49.6	1.70
Median Speed (MB/s)	7.8	6.3	26.0	1.59
Average Speed (MB/s)	**7.6$\pm$1.6**	**6.3$\pm$1.6**	**27.0$\pm$15**	**1.56$\pm$0.12**

2.6 Ongoing HPC projects

2.6.1 Land degradation assessment baseline report

A land degradation assessment baseline study was conducted for the Omusati region, a region in the northern part of Namibia. The project was carried out by the Ministry of Environment and Tourism in conjunction with UNAM's Department of Geography Information System and the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). The assessment was to quantify the land degradation in the region as well as recommendations on reducing further degradation of the land. To achieve this, the data was collected in the region in the form of soil samples for analysis on soil organic carbon. The analysis of these samples was carried out on the UHPC using the R programming language. The results were represented as a map showing different percentages of the soil organic carbon of the Omusati region, outlining which part of the region still has soil suitable for agriculture (Hengari et al., 2019).

2.6.2 Modelling of broadband emission of globular clusters

Globular clusters (GCs), spherically bound collections of stars, are among the most ancient of bound stellar systems of the cosmos and consists of about 10^4–10^6 stars (Ndiyavala et al., 2018). Terzan 5 is the only Galactic globular cluster that has plausibly been detected in the very-high-energy range. Data from the *Fermi* Large Area Telescope was used to calculate the broadband spectral energy distribution (SED) and then this SED was modelled. The emission is thought of as pulsed and un-pulsed emission. The pulsed emission is attributed to the embedded pulsars in the GC and the un-pulsed emission attributed to the interaction of the leptonic winds ambient magnetic and soft-photon fields (Ndiyavala et al., 2019). The HPC at UNAM was used to study the uncertainty in the model parameters and to demonstrate that

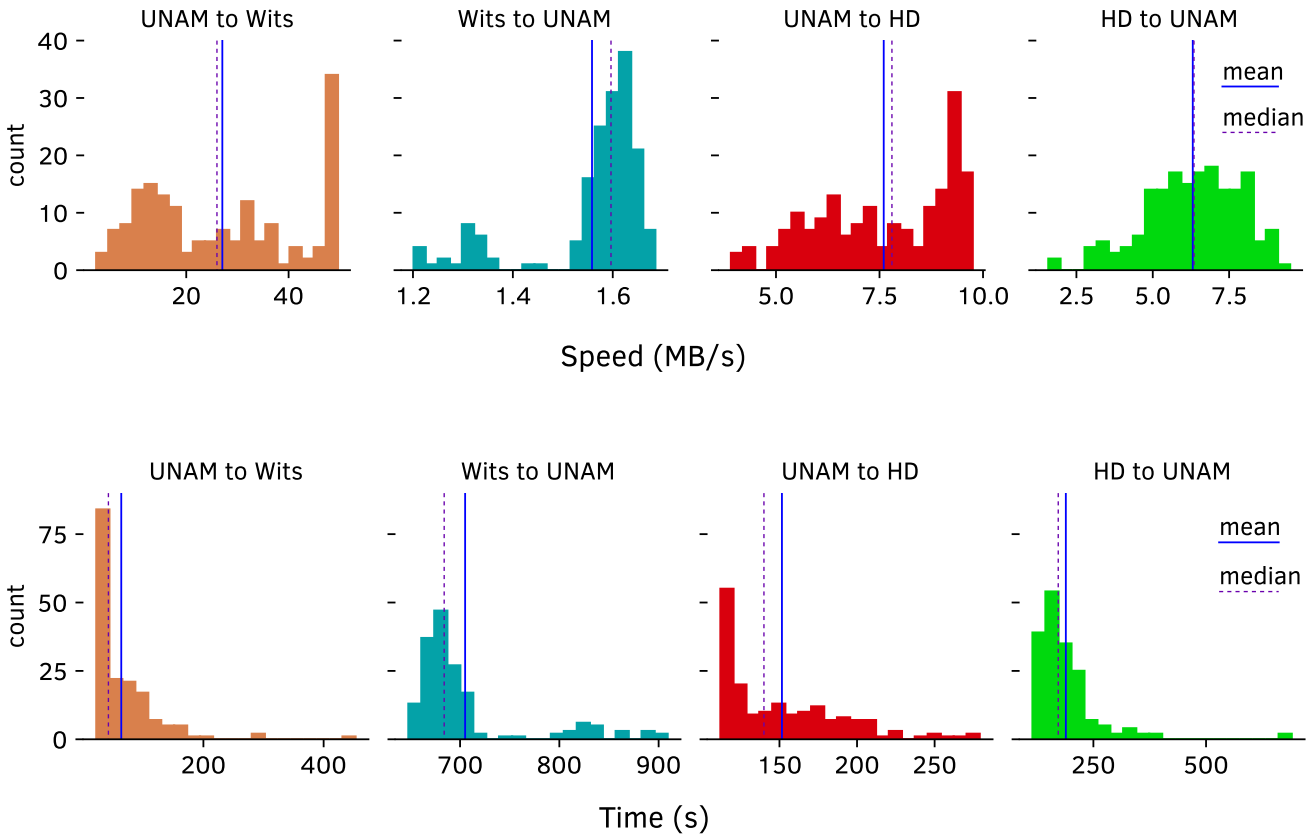

Figure 4: Distributions for the speeds and times from UNAM to WITS taken for the transfer of 1 GB for a period of one week, with the transfer taking place every hour. Most distributions are bi-modal or have distant outliers from the bulk of the data. Each histogram has a title that indicates which transfer it describes between the three clusters. Solid and dotted lines indicate the mean and median speed (or time), respectively.

this uncertainty leads to a large spread in the model predicted flux (Ndiyavala-Davids et al., 2021; Venter et al., 2022).

2.6.3 Analysis of gamma ray data of active galactic nuclei

The University of Namibia is a part of the High Energy Stereoscopic System (H.E.S.S.) (de Naurois, 2018) collaboration and thus has access to data from the array of five imaging atmospheric Cherenkov telescopes (IACTs). This data consists of, in part, images of the Cherenkov radiation produced when a highly energetic particle is incident on the atmosphere. The analysis of the data involves doing a pixel by pixel comparison of the data taken with simulated images so as to estimate the parameters of the incident gamma ray. A log-likelihood approach is taken for the parameter estimation. This is a computationally intensive analysis, given that

there are five telescopes (four with 960 pixels (Ashton et al., 2020) and one with 2048 pixels) each containing a large set of variables recorded during observation, that have to be compared to a large number of simulations done with different parameters, such as energy (of the incident particle), depth of first interaction, direction, etc. The UHPC has been configured to perform such analyses and already research projects for two master's theses (Nanghonga, 2020; Shapopi, 2019) and a bachelor's thesis (Brand, 2020) have been completed in that context.

2.6.4 Case study weather modelling

The Namibia Meteorological Services enlisted the UHPC to conduct weather modelling for particular weather events that occurred in Namibia. One such event was heavy rainfall that occurred in October 2018 around the north-western part of Namibia in the Kunene region. This particular event was of interest as it occurred after a long period of dry conditions, and resulted in more than 50 mm of rainfall in less than 3 hours, resulting in floods and the death of a number of animals. The Namibian Meteorological Services used the UHPC to simulate this event employing a weather research and forecasting system (Somses et al., 2020).

2.7 Human capital development

In Namibia, the concept of high performance computing in its universal meaning is relatively new. Thus, to take advantage of the new facilities at UNAM, training must be provided to build capacity in high performance computing. With this goal in mind, efforts have been made to grant training in the form of workshops and schools. The first workshop was held in February 2017 at the Namibia University of Science and Technology. The workshop was aimed at training system administrators in HPC and was facilitated by trainers from the South African CHPC. The workshop was attended by members from both universities, and consisted of people from computer science, physics, mathematics, and statistics. A second workshop was held at the University of the Witwatersrand, South Africa, in August 2017. This workshop was also aimed at training system administrators in HPC, and was attended by members from different SADC countries that are members of the SADC HPC Ecosystem Project. A series of sponsorships followed, where individuals were sponsored by STEM–Trek and CHPC to attend the Supercomputing conference held annually in the United States of America.

Another workshop for capacity building was held in September of 2018 in UNAM's School of Computing. In addition to this, there have been multiple schools that also gave introductory lessons on high performance computing, such as the biannual African School of Fundamental Physics and Applications, held in 2018 at UNAM (Acharya et al., 2018) and the Development in Africa with Radio Astronomy (DARA) project (Hoare, 2018), supported by the CHPC in South Africa, that has a yearly intensive program at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa.

There are now plans to hold more workshops aimed at creating awareness on the potential uses of HPC in Namibia as well as training more people in using and administering HPC systems. It is noteworthy that capacity building in high performance computing has been

bolstered by the DARA Big Data project which provides bursaries for students from the partner countries of the AVN (Scaife & Cooper, 2020). This project is made possible by a partnership between the UK Newton Fund, the Global Challenges Research Fund program, and the South African Department of Science & Technology. Given the computationally intensive nature of the field of Big Data, it is expected that many of the graduates from these scholarships will be conversant in high performance computing.

3 CONCLUSIONS AND OUTLOOK

Namibia's first HPC system is steadily growing with contributions and efforts from different organisations and is actively being used to develop human capacity. The UHPC facility intends to further leverage on the relationship with the South African Centre for High Performance Computing, in terms of support and training to further human capital development in HPC. Extensions to the UHPC that will be realised in the near future are listed below.

3.1 The UHPC/H.E.S.S. storage server

The High Energy Stereoscopic System in Namibia recently upgraded its on-site storage server (Zhu et al., 2021) and donated part of the former one (Balzer et al., 2014) to the University of Namibia. This consists of four modules, each taking 16 hard disk drives of 1 TB capacity, three modules, each taking 16 hard disk drives of 3 TB capacity, and 10 computing modules hosting *Intel Xeon e5450* processors. In total, this amounts to a storage capacity of 202 TB, which is a sizeable addition to the 13 TB storage space already available, and essentially positions UNAM well to host a subset of the entire H.E.S.S. data locally.

3.2 The UHPC/Stampede

UNAM also received a Dell PowerEdge C8220 *Stampede* rack with 40 computing nodes. Each compute node on *Stampede* has two Intel Sandy Bridge 80623 CPUs (eight cores each) with 32 GB RAM and 250 GB on-board storage. Once operational, the *UHPC/Stampede* will complement the *UHPC/Ranger* in boosting the capacity of the UHPC facility to offer state of the art computational needs not only to the UNAM community but to the Namibian community at large.

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We want to acknowledge the HPC Ecosystems Project at the Centre for High-performance Computing (CHPC) in South Africa for the provision of the Ranger and Stampede HPC racks as well as the Head Node and the Namibian National Commission on Research, Science, and Technology (NCRST) for facilitating the transport. We also want to acknowledge the donation

of the H.E.S.S. Storage Server by the H.E.S.S. collaboration. We want to thank the Max-Plank Institute for Nuclear Physics in Heidelberg, Germany, and the Centre for Astrophysics at the University of Witwatersrand in Johannesburg, South Africa, for granting us access to their clusters to perform data transfer tests. The support of Jim Hinton and Nukri Komin in this is highly acknowledged. The Virtual Institute for Scientific Computing and Artificial Intelligence (VI-SCAI) is gratefully acknowledged for operating the High Performance Computing (HPC) cluster at the University of Namibia (UNAM). VI-SCAI is partly funded through a UNAM internal research grant.

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Viewpoint

Developing an ontology-based system for semantic processing of scientific digital libraries

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ABSTRACT
The development of theories, methods, and algorithms for the discovery and formation of new knowledge remains one of the most important tasks for any researcher, especially if they are actively working to create new scientific publications. Yet, there is no universal language to describe full formal concepts (i.e. knowledge) or the systemology of transdisciplinary scientific research. Because of this, researchers face a set of urgent challenges. One such challenge is how to speed up the process of finding information in their own sources. To address this challenge, we created an ontology-related system for processing digital libraries of scientific publications. This system implements the technologies of information retrieval and knowledge discovery in digital libraries with an emphasis on technologies and instruments such as those used in the Semantic Web and cognitive graphics.

Keywords: Transdisciplinary research, Semantic Web, Ontology engineering, SPARQL, Digital library

Categories: • **Information systems** ∼ **Information retrieval, Document representation, Ontologies**

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1 INTRODUCTION

Many applications are available to search for information in different databases, and some are quite specialised. Most do not take into account the cognitive aspect of data processing that is needed for creative approaches, in particular for researchers.

A separate problem is the multimedia (conceptual and figurative) presentation of the search results, and their comparison with the conceptual structure of the subject area or knowledge domain. This interests us for the purposes of gaining new knowledge. For scientific research,

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it is relevant to process the scientific publications of one author, authors of a scientific unit, or of an institute by using the Semantic Web, known as Web 3.0 (W3C, 2023b), technology.

An ontology-related system (OrS) for processing digital libraries (i.e. databases or other types of digital repositories) of scientific publications (DLSP) uses technologies of information retrieval and knowledge discovery in databases with an emphasis on technologies and instruments of the Semantic Web and cognitive graphics (Palagin et al., 2014; V. Y. Velychko et al., 2014). This technology and corresponding instruments allow for the creation of multimedia presentations of conceptual and figurative structures, which are described in scientific papers. Semantic Web technologies allow for the creation and processing of the Resource Description Framework (RDF) (W3C, 2023a) repository of scientific publications, development of local and/or remote endpoints, and the assembling and execution of SPARQL-queries. Of the entirety of Semantic Web technologies, we need to highlight SPARQL-technology, which allows a researcher to create queries of arbitrary complexity and to receive a response that can include all kinds of information.

A generalised diagram for the development of OrS DLSP is shown in Figure 1, where SP denotes 'scientific publication'. It includes the preparation stage block and blocks of the main stage with variations A, B, and C. The preparation stage is described in detail in previous studies (Palagin et al., 2014; Palagin & Petrenko, 2020; Palagin et al., 2011) where ontology graphs of the subject area are provided. They serves as data for implementation of the main stage, variation *B*, *phase 2* (*B2*).

We can know about the personal knowledge database of a specific researcher, in which a sum of functional capabilities is declared. These capabilities support processes of scientific and creative activity. Such a personal knowledge database is:

- A tool that supports scientific research, and one of the central directions of practical informatics development (Palagin et al., 2017; Palagin et al., 2014; Palagin et al., 2020; Palagin, Velychko et al., 2018);
- A knowledge system development for researchers, for the purposes of new knowledge gain (or arrangement of existing knowledge, error checking and checking for contradictions, etc.) (Palagin, 2006, 2013; Palagin & Petrenko, 2018; V. Velychko et al., 2022);
- One of the main subsystems for the modern system of research design (Palagin, 2016; Palagin, Petrenko & Malakhov, 2018), and an automated workplace for researchers (Palagin et al., 2017; Palagin et al., 2020; Palagin, Velychko et al., 2018);
- One of the main elements for the creation of permanent canonical knowledge and support for knowledge-oriented information system functioning.

It is common knowledge that there is a tight connection between Semantic Web and Unified Modelling Language (UML) technologies. In particular, this is a connection between the Web Ontology Language (OWL) (W3C, 2022) syntax and the visual modelling of UML diagrams. UML is presented as a general-purpose language of visual modelling, which is developed for

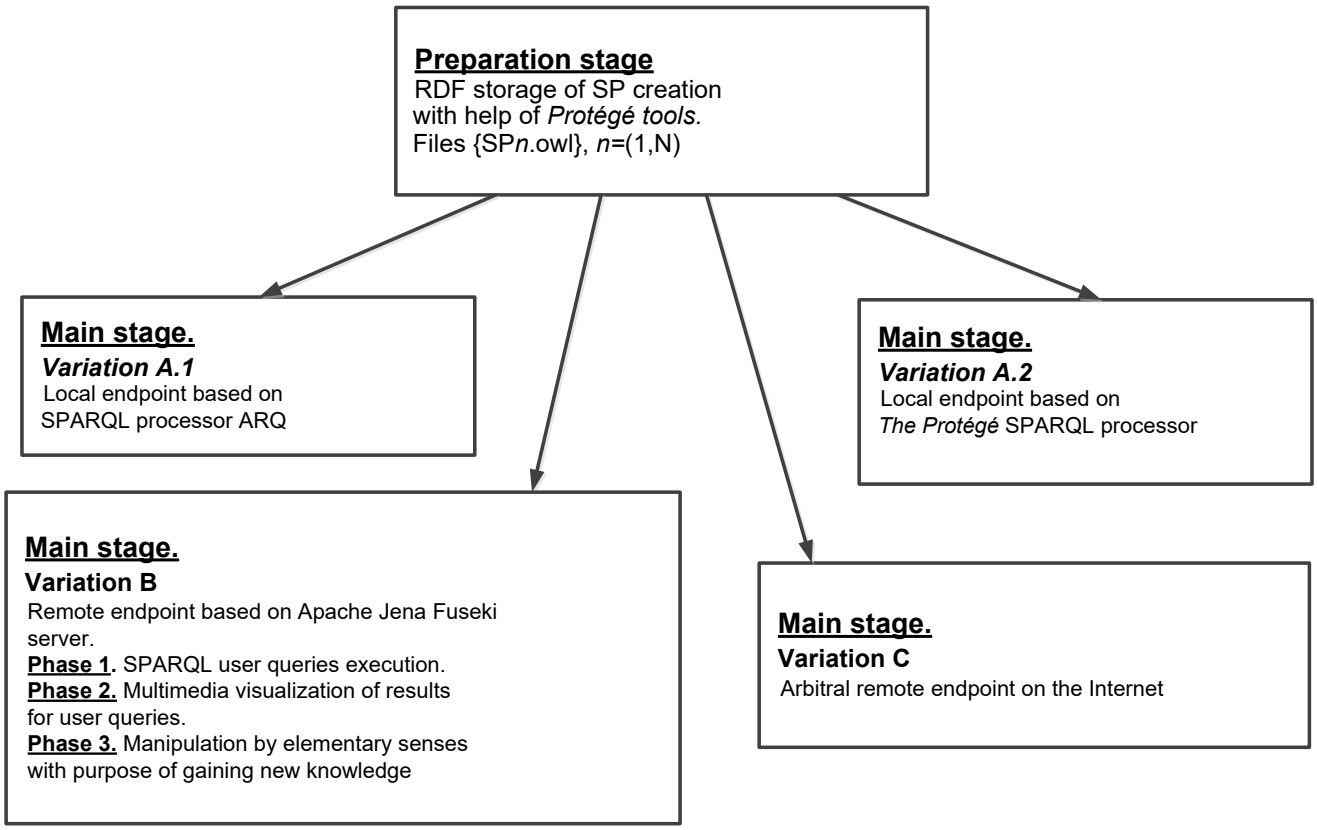

Figure 1: Generalised diagram of OrS DLSP development

the specification, visualisation, designing, and documenting of software components, business processes, and other systems (Booch et al., 2005). UML is an easy and powerful tool for modelling, which can be used effectively for the creation of conceptual, logical, and graphical models of complex systems that are built for different purposes. This language absorbed all the best software engineering methods and qualities, and has been successfully used for many years to model large and complex systems (Booch et al., 2005; OMG, 2022).

Visual modelling in UML can be presented as a process of a gradual descent from the most general and abstract conceptual model of the source system to the logical, and later physical model of the corresponding software system. For this purpose, a model in a form of a use case diagram is built first. This diagram describes the functional purpose of the system, and what this system will perform in a process of its functioning. A use case diagram is a conceptual presentation, or a conceptual model of the system in the process of its design and development (Schmuller, 1999).

An OrS "database of scientific publications" is created for an author who is actively engaged in the preparation and production of new scientific publications. Of course, searching through one's own scientific publications can be done manually, which in most cases is how it

is presently done. However, with the help of OrS, this search can be accelerated significantly. In addition, it is possible to automatically structure received data into appropriate templates for future scientific papers.

Now we will discuss the development of architectural, structural components, and UML diagrams. These diagrams show OrS functioning on the base of remote Apache Jena Fuseki (Apache.org, 2022a) endpoints. In addition, we will discuss examples of the formal description of scientific paper usage by performing a set of queries.

The goal of this article is OrS development. The system allows significant acceleration of information retrieval by an author (from his DLSP), provides a visual presentation of scientific publication concepts and respective subject areas, and implements the famous Brooks formula for acquiring new knowledge (Palagin, 2006; Palagin & Petrenko, 2018):

$$K\left(S\right)+dI=K\left(S+dS\right)$$

where $K\left(S\right)$ denotes the source knowledge structure, which is modified by results of information processing of portion dI, creating new structure $K\left(S+dS\right)$ with new knowledge portion dS. It is assumed that components dI and dS are closely tied with elementary senses – a simple two-syllable sentence with a direct object (Palagin & Petrenko, 2020).

The main stage of user task performance is split into three OrS architecture variations – *A*, *B*, and *C*. These variations have different functional power. *A* is the least powerful (organised as a local endpoint on the user's PC). *B* is of average power (organised as a remote endpoint based on an Apache Jena Fuseki server). *C* is the most powerful (organised as a remote endpoint, which is implemented with the help of original software). We can see that these variations of OrS realizations fit different purposes.

The *A* architecture scenario applies to one user in a local network with a knowledge engineer (*KE* is an expert in artificial intelligence language and knowledge representation who investigates a particular problem domain, determines important concepts, and creates correct, and efficient representations of the objects and relations in the domain). In this scenario, the user can form queries and receive answers only by working with one scientific publication at a time.

The *B* architecture scenario can be employed by a few users of the same scientific unit. When applying the *B* variation, it becomes possible to form one query for retrieval of structured information from multiple articles simultaneously, which is impossible to do with popular search systems.

The most powerful *C* architecture scenario can be used by users from an entire institute. The primary focus of this paper is to describe the processes with UML diagrams usage for variation *B*, *phase 1* (*B1*).

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2 ARCHITECTURAL AND STRUCTURAL ORGANISATION OF OrS DLSP (VARIATION B, PHASE 1)

For this variation, the OrS functions as a remote endpoint based on Apache Jena Fuseki (Apache.org, 2022a), and consists of three phases: *phase 1* – *SPARQL* (Apache.org, 2022b) user queries processing; *phase 2* – multimedia visualisation of user query results, or creation and usage of conceptual and figurative structures for the subject area; and *phase 3* – manipulation by elementary senses with the purpose of gaining new knowledge.

In Figure 2 the *B1* variation of the OrS is presented. Initially, the knowledge engineer downloads the relevant files and deploys Apache Jena Fuseki as a remote endpoint (DuCharme, 2013). The knowledge engineer then uploads scientific publications in the form of RDF graphs to the server; this data is generated in the preparation stage.

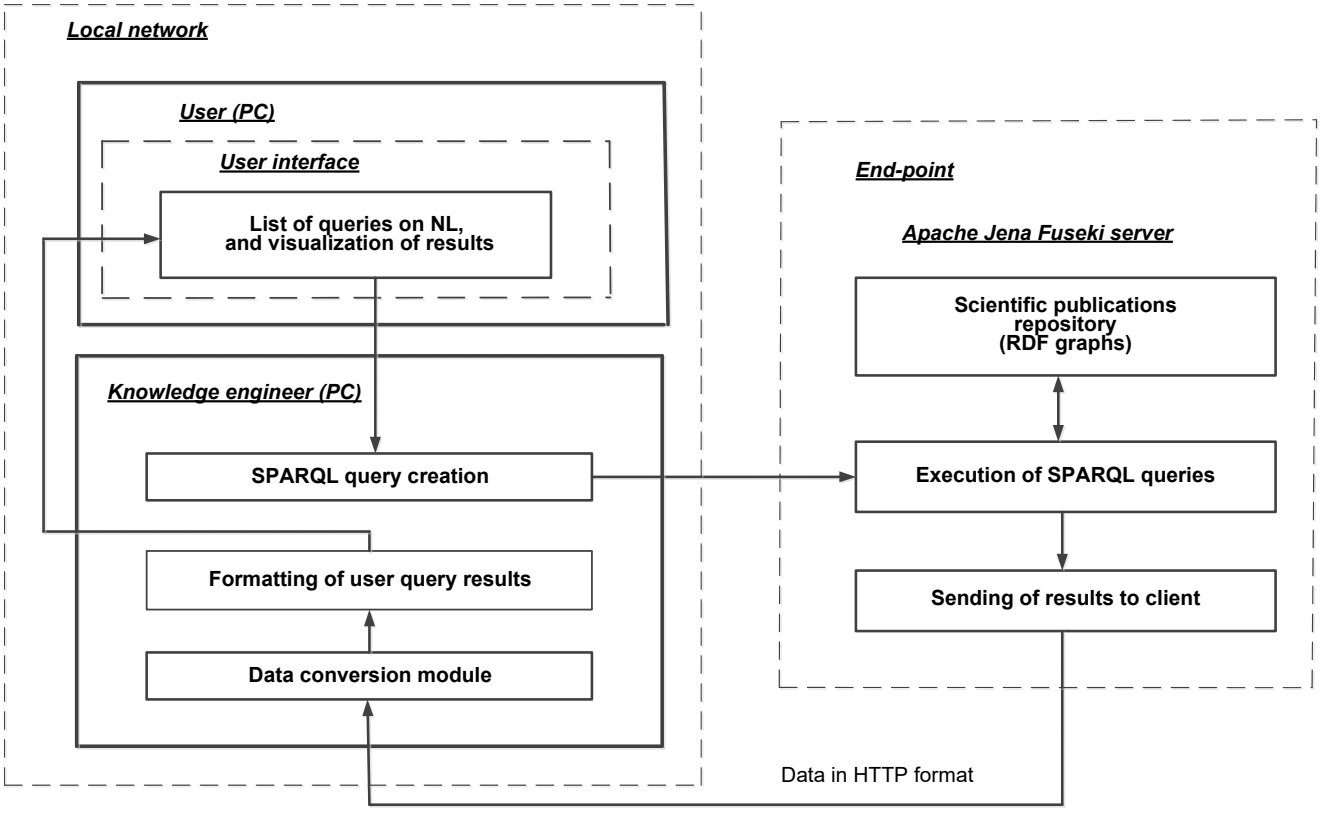

Figure 2: Generalised diagram of the *B1* variation of the OrS for processing digital libraries of scientific publications

The user can see the list of possible queries in natural language in their user interface. The user can choose any query from this list, one-by-one. The chosen query is transferred via the network to a knowledge engineer module. The user systematically validates the information

they are working with. Since it is possible to choose a subset of articles used for a search, this feature is useful if a researcher does not need to search in all databases.

2.1 Basic user queries

The researcher database contains *N* scientific papers published in popular scientific journals. Serial numbers of scientific publications (in this case we deal with articles) serve as arguments for queries and are numbered as follows:

$$m_1, m_2, \ldots, m_k, \ldots, N-1, N$$

Data is organised in such a way that the author of a scientific publication is the first co-author of the publication, or in another case, the author is the one who owns the database.

Below are examples of queries in natural language (NL).

1. Show titles of articles on the topic of “transdisciplinarity”.
2. Show titles of articles on the topic of “ontological”.
3. Show annotations of articles $m_1, m_2, \ldots, m_k, \ldots$
4. Show keywords of articles $m_1, m_2, \ldots, m_k, \ldots$
5. Show titles of all N articles:
   - 5.1. in the order of publication date
   - 5.2. without co-authors.
6. Show titles of articles $m_1, m_2, \ldots, m_k, \ldots$, where (query arguments are set by a user).
7. Show full names of co-authors for articles $m_1, m_2, \ldots, m_k, \ldots$

3 UML DIAGRAMS OF THE OrS FUNCTIONING FOR VARIATION B1

We now discuss UML diagrams, which reveal the core of OrS functions for variation *B1*.

Figure 3 is a use case diagram; Figure 4 is a class diagram; Figure 5 is a components diagram, and Figure 6 is a sequence diagram (Figures are in Appendix A).

A discrete number of researchers are connected to a local network, which is administrated by a knowledge engineer. We will discuss the network operation for one user; the processes are organised in a similar fashion for other users.

For researchers, the PC functions as the module of the general interface. All the queries on NL are displayed in the interface, from which the researcher can choose one with desired arguments; a different element of the interface shows results of the query execution.

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Another part of the system contains a module for the knowledge engineer. In this module, a *SPARQL*-query is formed out of the NL-query and transferred over HTTP protocol to the endpoint. On the Apache Jena Fuseki server, the *SPARQL*-query is executed and the response is sent via HTTP protocol to the knowledge engineer module and corresponding interface. The operation of forming and processing user queries, and receiving replies are shown in detail in the main UML diagrams in Figure 3 through Figure 6.

It is important to note that these diagrams do not show the process of argument selection and their transformation into article numbers in the database.

4 EXAMPLES OF SPARQL-QUERIES EXECUTION AND THEIR RESULTS

Below are some typical requests to the DLSP using the natural language requests and their corresponding representation in the form of *SPARQL*-queries. It is important to note that all NL and *SPARQL* queries are made to the digital library that contains articles in Russian and Ukrainian languages. The DLSP by Alexandr Palagin was taken as a basis for these examples. Requests to endpoints can be made either using the ARQ (Apache.org, 2022b) query engine or directly from the Fuseki user interface (which is shown in Figure 7). The Apache Jena Fuseki SPARQL server address is https://triplestorage.ai-service.ml/. Credentials for access can be provided on request.

Important note: The Jena Fuseki SPARQL server is in active development. For any technical clarifications and questions contact the first author via email. The recent Russian rocket shelling on critical infrastructure in Ukraine and Kyiv led to the shutdown of the https://triplestorage.ai-service.ml/ server.

SPARQL-query:

```
PREFIX
<http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
SELECT ?article_number ?article_title
{GRAPH ? article_number {?s1 : article_title ? article_title.
 FILTER REGEX(?article_title, "transdisciplinarity", "i")}}
```

Listing 1: **NL-query 1:** Show titles of articles on the topic of “transdisciplinarity” (results are shown in Table 1).

SPARQL-query:

```
PREFIX:
<http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
SELECT DISTINCT ?article_number? article_title
{GRAPH ? article_number {?s1 : article_title? article_title.
 FILTER REGEX(?article_title, "ontological", "i")}}
```

Listing 2: **NL-query 2:** Show titles of articles on the topic of “ontological” (results are shown in Table 2).

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SPARQL-query:

```
PREFIX:
<http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
SELECT ?article_number ?article_title (group_concat(?abstract) as ?abstract_full)
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article1>
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article2>
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article7>
{GRAPH ? article_number {?s1 : article_title ? article_title.
 {:Abstract : sentence_exists  ?sentence}
 {?sentence :text_exist ?abstract}}} group by ?article_number ? article_title
```

Listing 3: **NL-query 3**: Show annotations of articles 1, 2, 7 (results are shown in Table 3).

SPARQL-query:

```
PREFIX:
<http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
SELECT ?article_number ? article_title ? keywords
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article1>
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article2>
FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article7>
{GRAPH ? article_number { ?s1 :Keywords_title ?Keywords OPTIONAL
    {?s2 :article_title ?article_title}}}
```

Listing 4: **NL-query 4:** Show keywords of articles 1, 2, 7 (results are shown in Table 4).

Table 1: Query results for NL-query 1

article_number	article_title
article1	Methodological foundations of development, formation and IT support transdisciplinary research
article2	Transdisciplinarity, informatics and development of modern civilization
article36	Problems of transdisciplinarity and the role of informatics
article7	Introduction to the class of transdisciplinary ontology-driven research systems design

Table 2: Query results for NL-query 2

article_number	article_title
article5	About some features of the construction of ontological models of subject areas
article7	Introduction to the class of transdisciplinary ontology-driven research design systems
article8	Ontological concept of informatization of scientific research
article10	Architecture of ontology-driven computer systems
article16	On the issue of system-ontological integration of domain knowledge

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Table 3: Query results for NL-query 3

article_number	article_title	abstract_full
article1	Methodological foundations for the development, formation and IT support of transdisciplinary research	The foundations of the methodology of a transdisciplinary systematic approach to the formulation and implementation of scientific research and complex applied projects have been developed with an emphasis on their IT support using methods and tools of artificial intelligence, in particular, ontological engineering …
article2	Transdisciplinarity, informatics and the development of modern civilization	The prospects and problems of the development of human civilization have always worried society …
article7	Introduction to the class of transdisciplinary ontology-driven research design systems	The class of research design systems based on the use of paradigms of transdisciplinarity, ontological management and purposeful development is considered …

Table 4: Query results for NL-query 4

article_number	article_title	article_keywords
article7	Introduction to the class of transdisciplinary ontology-driven research design systems	transdisciplinarity, ontological management, virtual structures (paradigm), developing systems, noospherogenesis, noosphere, scientific picture of the world, transdisciplinary approach (knowledge), convergence clusters, ontological approach
article2	Transdisciplinarity, informatics and the development of modern civilization	transdisciplinarity, computer science, monitoring, convergence cluster, computer ontology, knowledge engineering, Unified National Informatization Network, global network of transdisciplinary knowledge
article1	Methodological foundations for the development, formation and IT support of transdisciplinary research	scientific picture of the world, information technology, developing information system, transdisciplinarity, transdisciplinary research, transdisciplinary knowledge, convergence cluster, ontology, ontological concept, ontology-oriented support

https://doi.org/10.18489/sacj.v35i1.1219

5 CONCLUSION

The goal of our research was to develop an ontology-related system for processing digital libraries (i.e., databases or other kinds of digital repositories) of scientific publications, which will allow researchers to significantly increase the retrieval speed of required information (in the form of cognitive structures) from their sources.

This article introduced and described the architectural and structural organisation of OrS, which includes the local network with PCs of user and administrator/knowledge engineer, and remote endpoints based on the Apache Jena Fuseki server. This was shown via core UML diagrams of OrS functioning and examples of user query execution.

6 FURTHER RESEARCH

This research is far from its end goal. As we explained, it is necessary to implement phases 2 and 3, and for that we need to develop algorithms of creation for conceptual and figurative structures; algorithms of their comparison; an analysis with the further intention of building subject area knowledge; and algorithms for the discovery of new knowledge following the Brooks formula.

In a future study, our team plans to implement the ontology-related system as a part of the knowledge-oriented digital library of the smart-system for remote support of rehabilitation activities and services (Chaikovsky et al., 2023; Malakhov, 2022, 2023; Malakhov et al., 2022; Palagin et al., 2022). Further research will aim to develop original instruments and tools with the purpose of optimising user queries, and optimising usability for ontology-related systems.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mykola Petrenko: Supervision, Conceptualization, Methodology, Writing – original draft, Validation. Kyrylo Malakhov: Software, Validation, Resources, Term, Writing – review and editing. Ellen Cohn: Writing – review and editing.

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- Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modelling, application ID: 2021.01/0136.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A APPENDIX

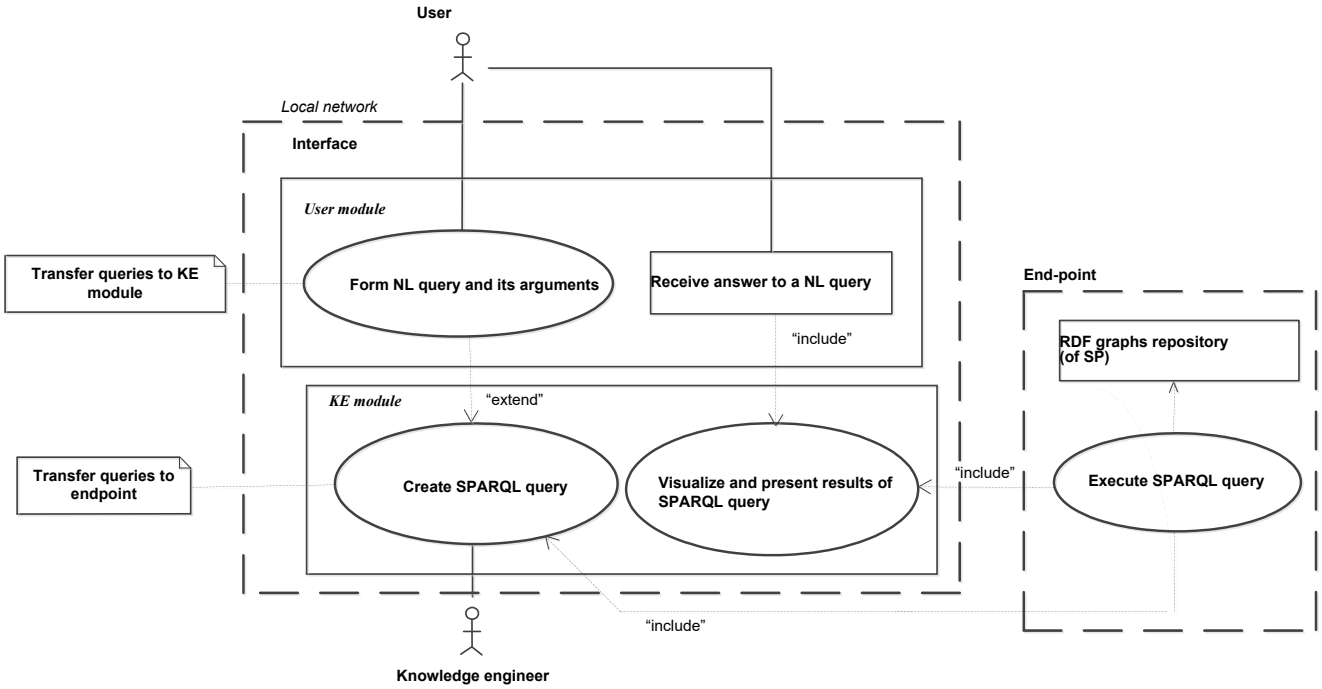

Figure 3: Use cases diagram of ontology-related system for processing digital libraries of scientific publications

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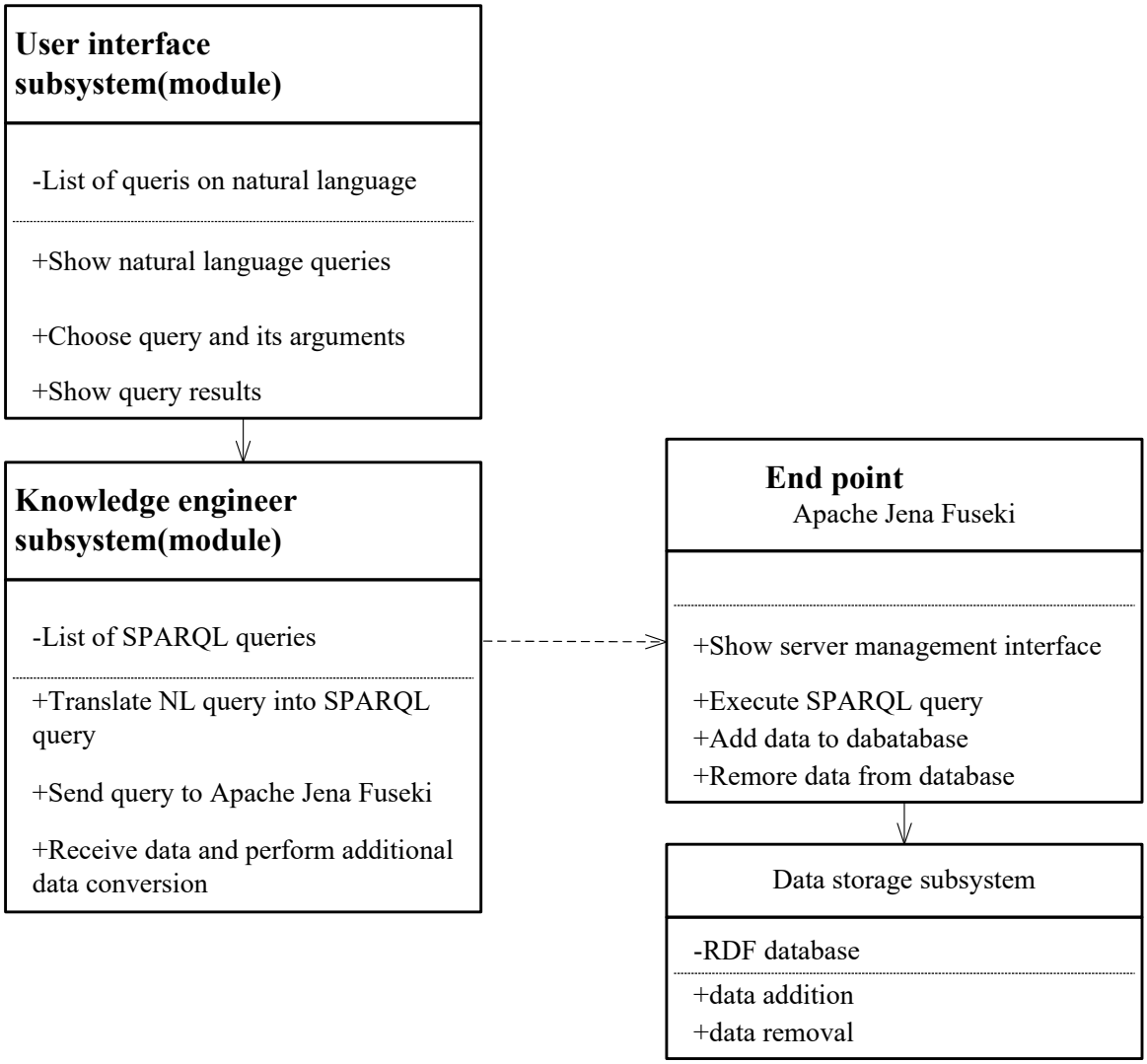

Figure 4: Class diagram of ontology-related system for processing digital libraries of scientific publications

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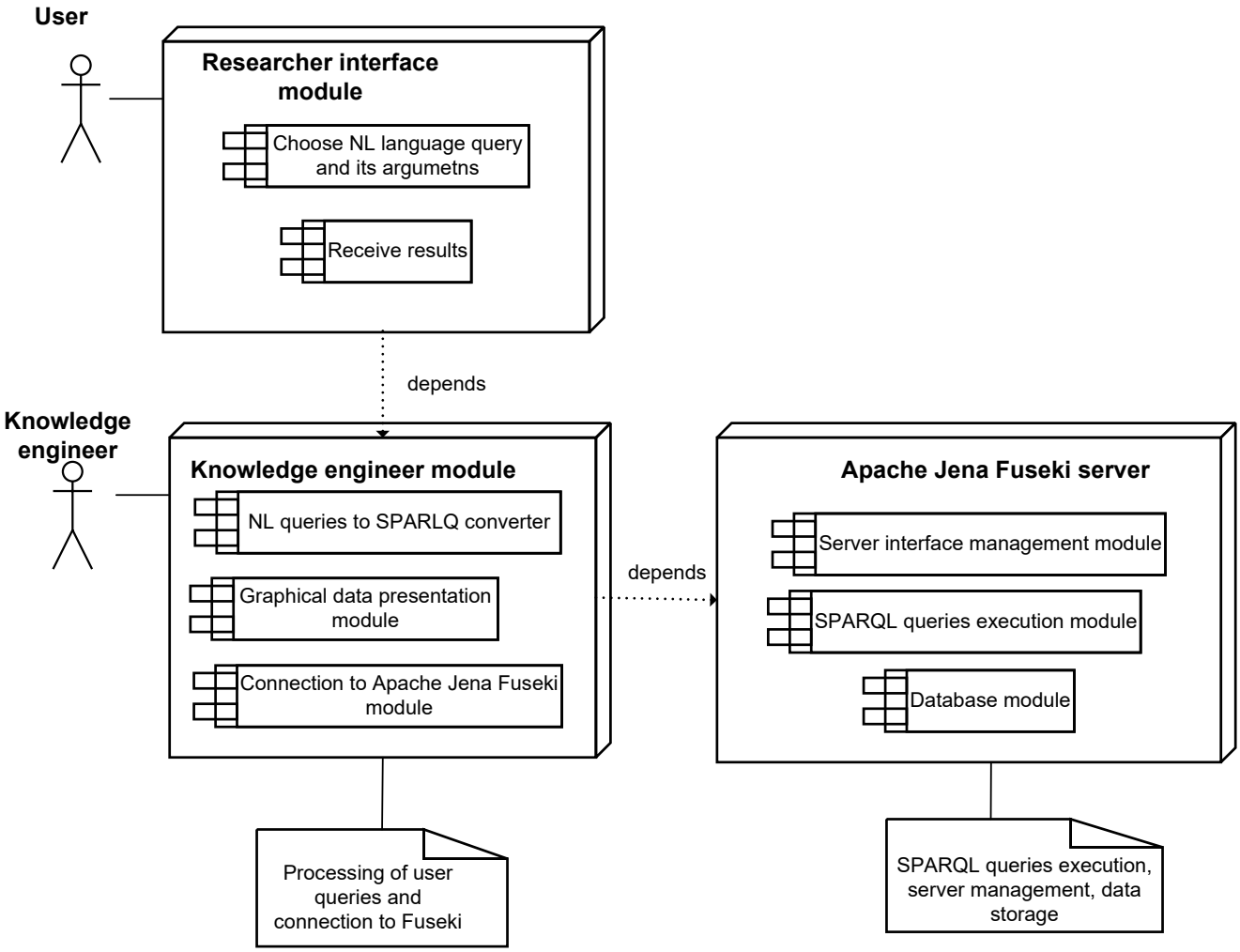

Figure 5: Components diagram of ontology-related system for processing digital libraries of scientific publications

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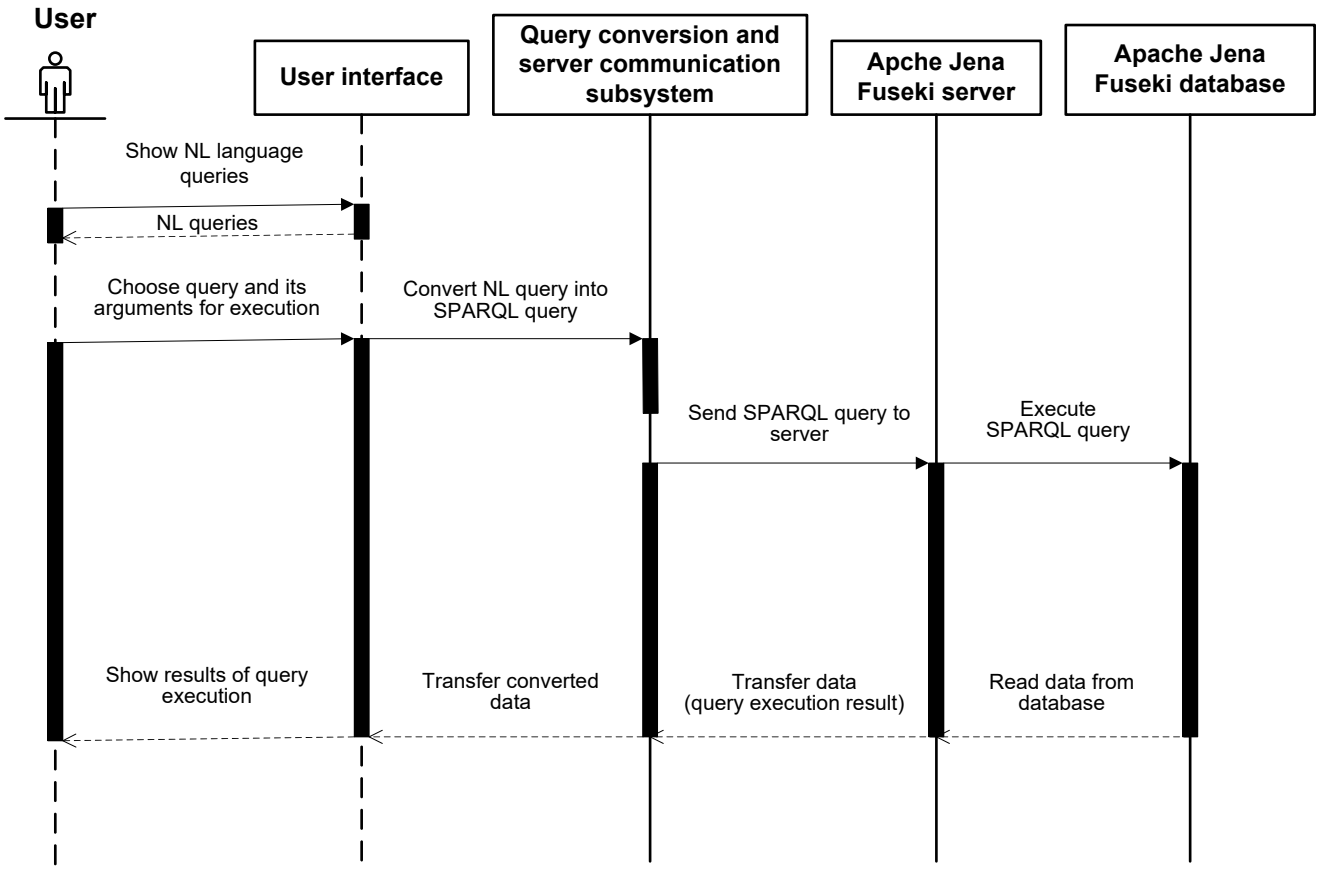

Figure 6: Sequence diagram of ontology-related system for processing digital libraries of scientific publications

https://doi.org/10.18489/sacj.v35i1.1219

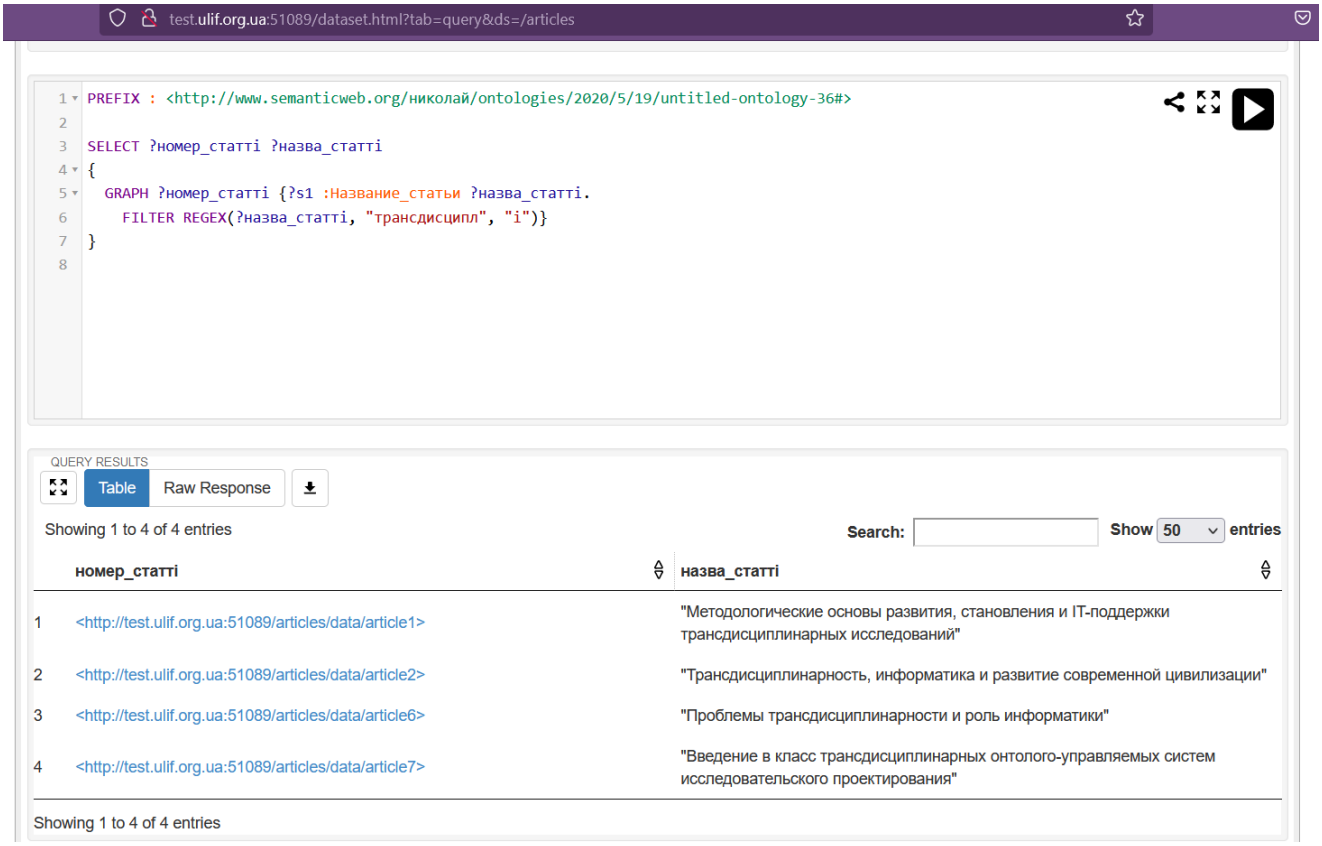

Figure 7: Fuseki user interface (NL-query: Show titles of articles on the topic of “transdisciplinarity”)

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Viewpoint

Ontology-driven development of dialogue systems

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ABSTRACT
A new technique and its software implementation are presented to create a deeply semantically structured ontology using plain natural language text as input, without regular structure or any previous tagging and markup. The new approach is primarily aimed at highly inflectional languages, and is implemented for Ukrainian. The automatically created ontologies (in OWL) could be easily converted to other graph databases formats, such as Neo4j, and were successfully evaluated as valid ontologies using Protégé, RDFlib and Neo4j environments. An integrated approach is proposed for the development of natural language dialogue systems driven by the ontology-related graph database using the Cypher language for the formal queries. The original phrases are subject to a special method of semantic analysis, which determines the type of formal query to the database. The essence of the analysis is that the text of the user's phrase goes through a series of checks. Based on their results, a set of basic templates for the formal requests are determined, as well as additional constructions that are attached to the basic template. Some of the checks may also return the notion of substitution to certain specified positions of the formal query. Formal queries can return both contexts and lists of ontology concepts. In addition to concepts, queries can also return information about specific semantic predicates that connect them, which simplifies the synthesis of natural language responses. The synthesis of answers is based on special templates, the choice of which is directly related to the corresponding template of the formal query.

Keywords: Ontology engineering, Ontology learning, Knowledge management, Knowledge base, Relation semantics, Neo4j, Cypher, Dialogue systems

Categories: • **Information systems** ∼ **Information retrieval, Document representation, Ontologies**

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1 INTRODUCTION

An essential element of every dialogue and reference system is its knowledge base (KB). The fundamental challenges in the design and development of information systems of this type are

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the structure of the KB, its fulfilment, development kits (devkits), maintenance, and interaction techniques.

Often, a deep scientific study and analysis is needed to comprehend the advantages and drawbacks of different approaches and find the optimal solution to some specific tasks set. The current research focuses on the questions of completely automatic creation of the KB (based on the natural language text with its structure and appropriate devkits) and method of subsequent interaction with the KB using a natural language interface.

Manual creation of a KB is a complicated, time-consuming, and complex process, which inspires finding techniques to automate the process. After automated creation, it might only take a minor manual correction and fine-tuning to make the KB more accurate. Furthermore, creating dialogue systems that can be *trained* by using natural language texts without any formal structure is highly desirable. Process automation will significantly assist in handling a large volume of data stored as plain text or collected via the Internet. This system could help users find answers to their questions as relevant contexts are extracted from texts. Also, users can get answers as inferences made from semantic data retrieved from the analysed text. The current state of computing and software techniques makes it possible to solve such a problem.

Ontologies are a well-known and proven method of organising semantically structured knowledge bases, which often comes with a particular type of graph database. Furthermore, given the specificity of the considered problem that involves dealing with natural language texts, which represent semantic structures by their nature, the use of ontologies appears to be an even more appropriate approach. Because one of the popular languages for ontology engineering is OWL (Antoniou & Plexousakis, 2016), which is a standard, it will appear as the foundation for ontology creation in this study. Moreover, conversion of OWL ontologies to other graph formats, for instance – the Neo4j graph database management system (GDMS) is possible.

Completely automatic ontology creation could be considered a specific type of machine learning which consists of semantic structuring of large amounts of textual information in a way that is acceptable for subsequent machine manipulation. This manipulation could be, for example, the automatic data collection from the Internet for a specific topic (knowledge domain). This direction in informatics is usually called *ontology learning* and has been actively developing in recent years. Automatic KB creation using natural language text is a specific type of machine learning.

Automatic ontology creation has been discussed in many studies (An & Park, 2018; Balakrishna & Srikanth, 2008; Elnagar et al., 2020). However, the development technique and structure of the ontology are highly dependent on the assigned purpose and knowledge domain. The original (native) natural language, its structure, and lexical and grammatical peculiarities also play a significant role in the approach to be developed. The implementations of most existing natural language processing (NLP), natural language understanding, natural language generation and natural language inference methods are devoted to the English language. This is because English has become the most widely accepted international language and the most useful in many branches of modern life. It should be noted that ontology learning approaches

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are not sufficiently developed for Slavic inflectional languages, e.g. Ukrainian. Our previous work (Litvin et al., 2021) is devoted to this question. However, the approach considered is only acceptable for previously tagged texts or text sets with a predetermined regular structure (such as official documents, letters, etc.). The technique presented in this study makes it possible to process texts without previous tagging and markup or regular structure.

The current study is devoted to the development of a reference system with a natural language (NL) interface, of which the main feature is the automatic building of the ontology-related graph through the semantic analysis of natural language text. A further part of the system provides natural language interaction with the graph database. The key concept is to convert user phrases into formal queries to the computer ontology. Since the system uses Neo4J as its core graph database management system, the Cypher language is used for the queries. The system also includes a module for the natural language generation of responses based on the results of a formal request. The current study primarily focuses on highly inflectional languages, which include East Slavic languages such as Ukrainian.

The core of the system is the computer ontology (in OWL) which is represented as a graph database dedicated to specific domain knowledge. This ontology must have a predefined structure to make it easier and more predictable to integrate with programs. Nevertheless, the specific content of the ontology is not predetermined and depends on the information from the text submitted as the input data. Thus, the outputs (responses) given by the system and its domain knowledge depend on the texts used as data for its learning.

It is important to note that the system proposed in this study intends to work primarily with the grammatically and orthographically correct text of scientific style and information technology domain knowledge.

2 STATE OF THE ART IN ONTOLOGY-DRIVEN DIALOGUE SYSTEMS AND ONTOLOGY LEARNING APPROACHES

The most important aspects covered in the study are ontology methods for the automatic generation of ontologies from natural language text, and their structural features; generation of formal queries, and natural language responses, mainly forming a natural-language interface of a graph database. Some of the relevant information on this topic can be found in our previous studies (Litvin et al., 2020, 2021; Palagin et al., 2014; Palagin et al., 2020, 2018).

Natural language dialogue systems, so-called chatbots, have a long history and a variety of approaches. In the following, we will review some examples of dialogue systems that have been developed in recent years, especially those that use computer ontologies in one way or another.

A typical example of a natural language dialogue system for English is described in Quamar, Lei et al. (2020) and Quamar, Özcan et al. (2020). The analysis of the user's input phrase assumes that English sentences have a fairly regular structure, which can be expressed quite well by a set of templates. Each of the templates has a constant part and some variables. The

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constant part indicates its basic semantic type (`intention`), and the variable parts indicate the places from which the corresponding concepts are to be extracted (placeholders). These placeholders are specified according to certain `intentions` of the concepts expected to be at the positions. We will consider an example from the aforementioned studies. Here is a template:

```
Show me {@M} by {@D} for {@V}.
```

The curly brackets here are the placeholders. The markers in the placeholders here indicate the following:

`@M` corresponds to the main requested concept;

`@D` is the selection category for concepts such as `@M`;

`@V` is the filter parameter.

To illustrate the idea, we consider a typical phrase, e.g.: `Show me admits by major diagnostic category for 2017`. It fully complies with the above template. The core entity that the user asks for is `admits` (in this case it corresponds to `number of hospitalisations`). The category of selection and sorting is `major diagnostic category` and the filter parameter is `2017`. The constant part of the template with certain positions and types of placeholders defines the corresponding `intention`. For each `intention` there is a corresponding set of database (DB) queries and instructions for displaying the results on the user interface. Databases for the main information storage are relational. The system also contains an ontology used to structure the categorisation of types and measurements of data stored in the main database. The `intentions` and concepts derived from the user's source phrase are compared with the ontology to determine those closest to the requested dimensions and categories from those available in the databases. One of the features of the system is that the ontology is automatically created based on a relational data model.

The approach presented here also focuses on the problem of pronoun substitution, which means the following: if a template variable appears to be a pronoun or just empty, the program uses the relevant data from the last of the previous queries. If there is no information in the previous queries, the default values are substituted instead of the pronoun. These defaults are formed on the basis of the most common queries collected during system usage. Currently, the system does not include automatic learning, although the authors have declared the possibility of its development in the future.

Some dialogue systems use an ontology as the main knowledge base. For formal queries, SPARQL is often used. Since the user interface assumes the use of natural language, one of the key tasks is the conversion of a natural language query into a formal query. One example of automated conversion of natural language queries into SPARQL frameworks is PAROT (Ochieng, 2020), which uses an approach that generates the most probable RDF triple based on the user's question. The triple is then validated by a special module that includes a dependency

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analyser to process user queries on RDF triplets. The RDF triplets obtained in this way are then transformed into ontological triplets using a special thesaurus. The generated ontological triplets are used to build a SPARQL query, which is used to obtain answers from the ontology. Testing of the PAROT framework by the author (Ochieng, 2020) showed that it has an accuracy of about 81–82% for simple questions, about 43–56% for complex ones, and for a specific thematic dataset (geography) the accuracy is increased to 88%.

Another example of an implementation of natural language conversion with SPARQL techniques is FREyA (Damljanovic et al., 2012), available on GitHub (V. Kumar, 2022). FREyA provides an interactive natural language interface for ontology queries. It uses parsing combined with ontology-based search to interpret questions and, if necessary, prompt the user. User choices are used to train the system, which improves the accuracy of its operation. This system is currently implemented for English only. In the GitHub repository (V. Kumar, 2022) some examples are given to illustrate how natural language questions could be converted to SPARQL using FREyA. Note that the FREyA configuration can be tuned to a specific ontology structure.

Another system is the LODQA (Linked Open Data Question Answering) system (Shaik et al., 2016) that accepts a natural language input query and returns SPARQL queries along with the corresponding responses. The system is composed of several modules. The first module processes the natural language input query. It is responsible for parsing and creating a graphical representation of the query, called a pseudographic template. The pseudographic template contains nodes and links. The nodes usually correspond to the basic name groups and the links to the dependencies between them. In addition, the pseudographic template indicates which node of the ontology graph is the focus of the query, i.e., what the user will get in response to the query. A pseudographic template is a search graph template of a target graph of RDF subgraphs that match it. However, it is called a pseudographic template because it is not yet based on the target dataset. As soon as the first module has generated a pseudographic template from the given natural language query, the next module is activated, which is responsible for finding URIs and node values in the pseudographic template. URIs and values must be present in the target dataset. For normalisation, each node of the pseudographic template is associated with the URI of the dataset. The concept in natural language could be normalised (reduced to its original grammatical form) in more than one way due to possible ambiguities. Therefore, more than one template could be obtained from a pseudographic template. The third module for the generated pseudographic template performs a search in the target dataset for the relevant parts, taking into account possible changes that may occur in the dataset. To account for structural differences between the bound pseudographic template and the actual structure of the target data set, this module attempts to generate SPARQL queries for all possible structural differences. SPARQL queries are then sent to the target endpoint, where responses are obtained and then returned to the user. These query arguments can be of a primitive type, such as `S, N, or NP`, or complex, such as `S/NP, or NP/N`. A slash means the argument should be displayed on the right, and a backslash means the argument should be displayed on the left. The system uses the following notation for parts of speech, e.g.: `NN` –

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noun, DT – definition (adjective), VB – verb. To facilitate the identification of RDF triplets, the words in the sentence are lemmatised and assigned the appropriate grammatical properties. The LODQA system currently only works with the English language. Detailed features of its operation are not given in Shaik et al. (2016), but are limited to a general description and analysis of working examples.

Although the development of dialogue systems, as well as the machine processing and *understanding* of natural language text, is mostly done for the English language, it is not limited to it. For example, Altinok (2018) presents a dialogue system for the German language, which uses an ontology to act as a dialogue manager (OntoDM) that maintains the state of the conversation. The ontology is also used as a knowledge base. These roles are combined. Domain knowledge is used to track objects of interest, i.e., ontology nodes (classes), which are products and services represented in the ontological knowledge base. In this way, the conversation history memory capability was introduced. A significant part of the article by Altinok (2018) is devoted to the peculiarities of linguistic problems of German language processing. At the time of the publication of byt Altinok (2018), the research work was still in progress and the criteria for the quality evaluation of the system had not yet been obtained. Another example is the article by Jung and Kim (2020), which describes the development of a dialogue system for the Korean language, which is fundamentally different from European languages.

One of the most promising graph database management systems is Neo4j (Goel, 2015; Helou et al., 2019), which provides relatively high performance as well as scalability and is suitable for working with large amounts of data. It is also currently one of the most popular graph databases. The formal query language used in Neo4j is Cypher. It has a wide range of capabilities, is quite flexible, and is open to adding functionality through plug-ins, such as the implementation of typical algorithms on graphs. However, unlike SPARQL, there are currently not many developments to convert natural language queries to formal queries in Cypher, with the exception of Sun (2018) and Srinivas (2023). The system proposed by Srinivas (2023) is rather primitive as queries must have a predefined structure. This approach is close to the one presented by Quamar, Özcan et al. (2020): a set of sentence templates in natural language, where some fragments are replaced by a special notation, as places from which the concepts are to be extracted for substitution in a query template. Each such template sentence corresponds to a specific query pattern on Cypher. The main advantage of the described approach is its simplicity, while the main disadvantage is that a real dialogue system requires a large number of such sentence templates containing all possible query options. Moreover, this approach is justified for languages with a regular sentence structure, such as English, where fewer phrase patterns are needed. Inflectional languages, e.g. Ukrainian, have a complex sentence structure with relatively free word order. This fact significantly increases the number of required templates.

Another important concept to be considered here is called ontology learning (OL), which aims to automatically or semi-automatically discover ontological knowledge from various forms of data and can overcome the bottleneck of ontology acquisition in ontology development (Zhou, 2007). The term *o*ntology learning had its origins in 2000 when Maedche

and Staab (2001) introduced it as a newly emerging field of research aiming at nothing less than the automatic generation of ontologies (Watrobski, 2020). Ontology development still faces some challenges, such as knowledge acquisition and the lack of sufficiently validated and generalised development methodologies. Zhou (2007) introduced the concept of rapid ontology development (ROD). It consists of three phases: design, learning, and validation. The design phase involves the identification and detailed analysis of domains, requirements, and relevant resources with the help of users and/or domain experts. A variety of techniques can be used for domain analysis, such as interviews, questionnaires, and informal text analysis. In the learning phase, appropriate learning techniques are selected, implemented, and then applied to discover ontologies from domain sources. The learning results are evaluated and refined in the validation phase, where the discovered ontologies are checked for redundancy, conflicts, and/or missing information. The active involvement of users and domain experts is highly desired in this phase. ROD is an iterative process that is repeated until the result is acceptable to users and/or knowledge engineers. The framework for ontology learning consists of information extraction, ontology discovery, and ontology organisation. Ontology discovery here means that supervised and unsupervised learning algorithms have been applied to discover ontological concepts and relations from the extracted information.

The ROD approach is neither new nor the only existing technique of OL. The process of ontology learning is performed in an automatic or semi-automatic way using several sources, with an insistent need for human involvement (Navarro-Almanza et al., 2020). Fully automated approaches are available, but they are still difficult tasks because in most cases human involvement is required. OL systems can be categorised according to the type of data they learn from Ma and Molnár (2020). These data types are unstructured, semi-structured, and structured (Faizi et al., 2020; Konys, 2017; Watrobski et al., 2014). More specifically, ontology learning methods can be classified according to the technique used, specifying the following solutions: methods and utilities for ontology learning from semi-structured schemas, knowledge bases, text, dictionaries, relational schemas, the Web, social data, and across languages, based on term extraction and concept formation, based on relation discovery (Ibrahim et al., 2023; S. Kumar & Kumar, 2022; Sivasubramanian & Jacob, 2020). These approaches can also be distinguished based on statistics, rule-based approaches, hybrid techniques, linguistic techniques, as well as logical techniques and resources (Ibrahim et al., 2023; Konys, 2015; Konys, 2017; Konys & Drazek, 2020; S. Kumar & Kumar, 2022). These solutions use different techniques depending on the different goals to be achieved. Depending on the results, these approaches differ depending on the techniques used. Some of them start to create an ontology from scratch, while others import and use existing ontologies. In addition, ontology learning systems differ in the degree of automation from semi-automated, collaborative, or fully automated (Konys, 2015; Konys, 2018; Konys & Drazek, 2020). Watrobski (2020) reports that there are at least 22 different approaches to OL today.

The OL methods that are closest to the scope of our study and are of interest to many researchers are those that use natural language text as an input source. Among the techniques used for this purpose are various combinations of NLP approaches, machine learning

(including deep learning), knowledge extraction using through patterns, semantic similarity metrics, clustering methods, statistical approaches, word patterns, etc. In the current research, a method is considered, which is primarily aimed at highly inflectional type languages, in the core of which there is a rule-based statistical analysis, which provides information about the semantic relations between entities mentioned in the analysed text. The information obtained in this way will be used to create an OWL ontology.

Thus, the main purpose of this research was the development and study of methods for automatic generation of ontologies from a natural language text, focusing primarily on highly inflectional types of languages, e.g., Ukrainian, and its subsequent use as a knowledge base in dialogue and reference systems using Neo4j and the Cypher query language.

Each of the main parts forming the system is considered in the next section: automatic generation of the ontology, natural language interface of the graph database and synthesis of responses in natural language using the results of the formal query.

3 PROPOSED APPROACH TO ONTOLOGY GENERATION FROM PLAIN NATURAL LANGUAGE TEXT

A complete description of the technique of automatic ontology creation based on a natural language text is given in (Litvin et al., 2020, 2021). Let us consider the ontology structure itself in terms of OWL.

In the proposed basic approach, there is a rule-based syntax-semantic analysis method. It is known that in highly inflectional languages, the main role of words bounding in a sentence belongs to the combination of certain flections (changeable endings of words). A developed language system of highly varying flection combinations for different parts of speech allows the expression of considerable semantic information. Thus, mere analysis of word forms for compatibility checking has the potential to bring not all, but a significant part of semantic information.

In the considered approach we have proposed about 90 semantic types, each of them actually could have several (up to more than a hundred) sub-types depending on such additional characteristics such as gender, tense, number, or a certain preposition for each of the words from the considered pair. However, these additional sub-types are not used in ontology creation, but they may be useful in the future for even deeper and more precise information structuring. Moreover, they come directly from the so-called `correlators`, which are the parts of the analyser that give the programs the options of how one or another semantic type could be expressed. There are several systems of semantic types. The set considered here could be derived from the astigmatic basis set by the method proposed in (Litvin et al., 2020, 2021).

The creation of an ontology from a text includes two key operations, which are performed by separate program modules. The first, probably the most important and the most resource-consuming part consists of the syntax-semantic analysis of the input text. The corresponding

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program module contains a manually created set of so-called `correlators` and `determinates`.

The `determinates` represent combinations of possible flections of words and prepositions between them (if any) corresponding to each option of semantic sub-types. They also indicate whether the combination is inverse and which of the words in the pair is to be considered the main one. The labels of the semantic sub-types are given as contention symbols, e.g. `K1001, K4801, K6201`, etc. An example of a line from the `determinates` file for the Ukrainian language is shown in Listing 1.

```
1 ім під ям  L   I   K6201K8644K8646
```

Listing 1: An example of a line from the `determinates` file for the Ukrainian language

Here we can see flections for the first and the second of the possibly related words *ім* and *ям*. The preposition *під* is assumed to be between them. The symbol `L` marks that the main word is the left one, as the given flections, and the symbol `I` says that the link is inverse. The possible semantic sub-types for the combination are designated as `K6201, K8644, K8646`.

The `correlators` represent the correspondence of each of the semantic sub-types to the possible options of parts of speech combinations, including their order in the pair. In addition, the verbose names of the semantic types (`macro types`) are given. For each of these `macro types` there may be several (up to more than a hundred) suitable sub-types. An example of a line from the file of `correlators` for the Ukrainian language is shown in Listing 2.

```
1 K3506 отделимостьдействия_ S4S1;S4S6;S4S13;S4S5;S4S3;S4S10;S4S11;S4S12;S4S18;S4S22;S4S25
```

Listing 2: An example from the file of `correlators` for the Ukrainian language

Here we have K3506, which is a semantic sub-type label. Then there is *отделимость_действия* (Engl.: separability of an action), which is a verbose name of the corresponding semantic *macro type*. Then there is a sequence of possible parts of speech pairs given as contentious symbols. For example, `S1` is a noun, and `S4` is a verb. The pairs are separated by semicolons.

Also, the program has a dictionary including word stems, lemmas, and flections. The dictionary gives the correspondence between stems, lemmas, and sets of flections. The dictionaries are stored in a special compact format and could be created automatically using open-language data.

The main purpose of the program is to use these data and the input text to find and typify the words in it, to determine stems and flections, to recognise the links between the words, and to find out their semantic types. The other result of such an analysis is obtaining the related word groups in the sentences. Formally, a group is a fully connected graph. Practically such groups could correspond to a whole simple sentence, a part of a complex sentence, or a participial sub-phrase. The outputs of this module are two XML files *allterms.xml* and *parce.xml*. They are used for the subsequent creation of the OWL ontology.

The *allterms.xml* file is just a list of terms – nouns and groups of names found in the analysed text with some of their properties. It consists of two main parts: `<terms> and <phrases>`. The first one contains terms. An example of how a term is displayed is shown in Listing 3.

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```
<term>
    <ttype>Noun_noun</ttype>
    <tname>тіло людини</tname>
    <wcount>2</wcount>
    <osn>тіл</osn>
    <osn>люд</osn>
    <sentpos>1/1</sentpos>
    <sentpos>1/2</sentpos>
    <reldown>2</reldown>
    <reldown>4</reldown>
</term>
```

Listing 3: An example of how a term is displayed in *allterms.xml* file

The <ttype> tag specifies the sequence of parts of speech that form the term. The <tname> tag is the text of the term as given. The <wcount> tag indicates the number of words in the term. Tags <osn> are given for each of the words and represent stems. Tags <sentpos> indicate the position of the words in the text (the sentence number, from 0 / the word position in the sentence, from 1). Tags <reldown> and <relup> are optional. They show the relations of the considered term to other terms in the file. Tag <reldown> points to the term of the narrowing context - any of its words could be found in this term, but the considered term contains more. The <relup> tag points to the term of expanding context – contains all words of this term and some others. Tags <reldown> and <relup> help to build a hierarchy of terms in the created ontology.

The <sentences> tag part contains only the texts of all sentences from the considered text in the <sent> tag.

The file *parce.xml* represents the syntax-semantic scheme of each sentence of the text. The sentence structures are given in container tags <sentence>. This container contains the following tags: several <item> tags representing the words and their properties; <sentnumber> – the number of the sentence in the text (from 1); <sent> – the text of the sentence. An example of the <item> tag is shown in Listing 4.

```
<item>
    <word>Книга</word>
    <osnova>кни</osnova>
    <lemma>книга</lemma>
    <kflex>а</kflex>
    <rel_type>К0</rel_type>
    <flex>га</flex>
    <number>1</number>
    <pos>1</pos>
    <group_n>1</group_n>
    <speech>S1</speech>
    <relate>0</relate>
</item>
```

Listing 4: An example of the <item> tag in *parce.xml* file

The <word> tag contains the text of the word as it appears in the current text. The <osnova> tag represents the root of the word. The <lemma> tag gives the lemma, the dictionary form of the word. Tags <kflex> and <flex> are flections. <kflex> – is just the ending, but <flex> is the part of the word that could be changed. The <number> tag is the

number of the word in the phrase. The `<group_n>` tag indicates that the word belongs to a group associated with the phrase. The `<speech>` tag contains the mark of the corresponding part of speech. The `<relate>` tag indicates the number of a word from which there is a semantic relation to the considered word. If the word has no incoming relations, as in the example above, its value is set to zero. And the `<rel_type>` tag is the type (sub-type) of the semantic relation. The `Ko` value means the absence of the relation or its unknown type.

The *allterms.xml* and *parce.xml* files are used to create an OWL ontology. Before describing the technique of its creation, let us consider the appropriate structure of the ontology that we are going to generate.

The ontology consists of classes and properties. The main classes are `Action`, `Adjective`, `Adverb`, `Name`, `Number`, `Preposition`, `Term`, `Negation`, and `UndefinedEntities`. So, we can see those ontology entities are sorted by their parts of speech. Subclasses of the class `Term` are the name groups and nouns with a hierarchical structure. Descendants of the `Name` class are given names. The most important properties are as follows: `SentenceGroups`, `Groups`, and `WordsLink`. The descendant properties of `WordsLink` are the semantic types. In certain ontologies, not all 90 of them may be presented, but only those that appear in the considered text. The descendants of these properties are certain links between entities (represented by classes). The *domain* of such a property is the main word in the linked pair, and the *range* is a dependent one. The property groups' descendants represent the linked groups of sentences. They can have types specified in their range field. It can be *subordinate*, *participial* or just nothing for other cases. The property `SentenceGroups` descendants represent the sentences, and descendants are subsequently linked to word groups.

With the two files mentioned and the file with `determinates` containing the verbose names of the semantic types, it is not difficult to create a short-described ontology. All OWL entities are first created as OOP representation objects. The root classes and properties are created first and are mandatory. Then a hierarchical structure of terms (nouns and name groups) is created using the *allterms.xml* file. Then, using *parce.xml*, the classes of other types of words and properties corresponding to the relations between words are created. At the same time, properties of type `WordsLink` are created, representing the semantic types. Since only one sub-type is specified in the *parce.xml* file, `determinates` are used to determine the semantic `macro type`. Since the words belong to the associated groups and these to the sentences, this information is used to create corresponding `Groups` and `SentenceGroups` sub-properties. The `Groups` and `SentenceGroups` descendant properties are supplemented with a label that contains the text of the corresponding group or sentence. These contexts seem to be useful for more informative ontology responses. The typing of the related word groups is done by the presence of certain words in the group: subordinating union, participle, and gerund.

The Neo4J GDMS could be used to work with the ontology of the described type. For this purpose, an OWL file should be loaded into it using the *Neosemantics* plugin. In this case, classes and properties become graph nodes of the corresponding type, which are `Class` and `Relation`. Relationships between nodes can be of the following types `SCO` - a subclass of;

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SPO - a sub-property of; DOMAIN; RANGE. The Cypher language is used for queries.

4 ANALYSIS OF THE USER INPUT PHRASE TO GENERATE CYPHER QUERIES TO THE NEO4J ONTOLOGY REPOSITORY

In highly inflectional languages, word order is less important than the fact that a word exists in a certain form. In this case, it may be sufficient to perform a series of tests on the sentence in question to verify several criteria. Based on the test results it may be possible to determine some semantic information and the entities (words, name groups) used to represent it. In the simplest test version of the system that exists now, there are the following main checks:

1. Question word – 6 lists + absence of such word. The result is the number of sufficient lists from 1 to 6 or 0 if there is no question word in the sentence. It can be not a single word but a combination of words, which is used as a marker of a certain type of question.

2. One word from given lists (most of them are specific verbs) – 6 lists + absence of words from all lists. The result is the number of the sufficient list from 1 to 6, from 0 – if there are no such words in the sentence. The words that clarify the general semantics of the sentence, such as location, aim, way of doing, etc., are checked here.

3. A noun in the nominative case, excluding words from the check (2), if there are any. The result can be 1 - there is such a word (+ the word itself) or 0 – there is no such word. Several entities can be selected from the phrase.

4. A verb, except those from the lists in check (2), if any. The result can be 1 – there is such a word (+ the word itself) or 0 – there is no such word. Several entities can be selected.

Even this short test has a large number of variants (196) for the possible results, making it possible to have several templates or different types of templates.

However, even this is not enough. Therefore, an additional check should be done to find some additional relations in the analysed sentence. The procedure is as follows: adjectives related to the word from sentence (3), which must be close to it and match it in number and gender; nouns in indirect cases (they form the basis of the additional relations) and adjectives related to them; and last but not least, checking the presence or absence of negation predicates. According to the results of these additional checks, the modifier templates can be selected to be added to the base template.

The templates are stored as XML files with a special structure. An example of one of the simplest templates is shown in Listing 5.

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```
<template>
    <verbose_name>Common information</verbose_name>
    <id>1</id>
    <type>base</type>
    <variables>
        <variable>
            <name>INPUT_VALUE_1</name>
            <destination>input</destination>
        </variable>
        <variable>
            <name>CONTEXT</name>
            <destination>output</destination>
        </variable>
    </variables>
    <match>
        (inp:Class)-[]-(n:Relationship),
        (n:Relationship)-[]-(x:Class),
        (n)-[:SPO]->(rel_group),
        (rel_group)-[:SPO]->(rel_sent),
        (rel_sent)-[:SPO]-(sent_super)
    </match>
    <where>
        inp.label = "INPUT_VALUE" and
        sent_super.name = "SentenceGroups"
    </where>
    <return>
        DISTINCT rel_sent.label as CONTEXT;
    </return>
</template>
```

Listing 5: An example of XML template for Cypher query formation to obtain contexts which include the given term

While the given template is one of the simplest, it is clearer to explain its general structure. The chapters of the XML template `<match>`, `<where>`, and `<return>` correspond to certain sections of a Cypher query (Jung & Kim, 2020). The template contains variables. They are described in the `<variables>` block. Each variable is defined by its name and its binding in the corresponding XML containers. The binding can have the values `input` or `output`. The input variables are to be replaced with the values of the input parameters during query generation. The output ones define the parameters to be obtained as a result of the query execution. The `<id>` container is required for the template identity and is used to search for it. The `<verbose_name>` tag is not used by the program but helps a human to easily identify it during system development and maintenance. The `<type>` tag indicates the type of template - base or additional. An example of a base template is given in Listing 5.

Let us look at the structure of additional templates. An example of one of them is shown in Listing 6.

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```
<template>
    <verbose_name>Adjective linked to subject</verbose_name>
    <id>1</id>
    <type>additional</type>
    <variables>
        <variable>
            <name>INPUT_VALUE_ADJ</name>
            <destination>input</destination>
        </variable>
        <variable>
            <name>ADJ_PLUS</name>
            <destination>intermediate</destination>
        </variable>
        <variable>
            <name>INP_ADJ</name>
            <destination>intermediate</destination>
        </variable>
    </variables>
    <block_union>and</block_union>
    <next_item_union>or</next_item_union>
    <match>
        (inp:Class)-[]-(ADJ_PLUS:Relationship),
        (ADJ_PLUS:Relationship)-[]-(INP_ADJ:Class),
        (ADJ_PLUS)-[:SPO]->(rel_group)
    </match>
    <where>
        INP_ADJ.label = "INPUT_VALUE_ADJ"
    </where>
    <return></return>
</template>
```

Listing 6: An example of an additional XML template aimed at the addition of some conditions related to the subject adjectives' presence

The template in Listing 6 also has `<match>`, `<where>`, and `<return>` blocks. Their content is not independent but should be added to the appropriate parts of a query formed by the base template. In this case, some of the sections may be empty. The main feature of an additional template is the presence of blocks `<block_union>` and `<next_item_union>`. The `<block_union>` tag indicates how the `<where>` block must be united with the query formed by the base template. The `<next_item_union>` tag specifies the union type for the repeated elements of the `<where>` block in the case where the corresponding variable is presented as a list (array). For example, the `INPUT_VALUE_ADJ` variable could correspond to several adjectives associated with the object. The values of `<block_union>` and `<next_item_union>` could be *and* or *or*. Also, the variables of the additional templates can have the third type of `<destination>` - *intermediate*. Such variables do not participate in the transfer of values to the forming query, nor the return of results. They are only used to mark the template parts that should not be duplicated during the part repetition. They are implemented with an order number, for example, `ADJ_PLUS_1, ADJ_PLUS_2, ADJ_PLUS_3`, ..., etc.

Let us take a closer look at the structure of formal queries and how they are created. The presented structure of the ontology makes it possible to search for contexts or individual terms. It has allowed not only the presence of some entities in the considered context but also their relations according to a certain semantic category. In the presented scheme there is a basic

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query template, aimed at obtaining information of a certain type in a given form, and an additional modifier template, which optionally adds the description of additional conditions. The above template is aimed at obtaining a context containing a specific term (word). However, the term must not only be presented in the context but also form a link with others, which could guarantee that the term is *organically* implemented in the context.

From here on, most of the query template examples here are given in a simplified format - without XML tags. Cypher queries are divided into three main parts: `MATCH`, `WHERE`, and `RETURN`. The `MATCH` block specifies a pattern for linking the nodes in the oriented graph. The `WHERE` part specifies the conditions that characterise the entities (nodes and relationships) from the `MATCH` case. The `RETURN` block shows what is to be returned as a result and with what names (aliases). In the example in Listing 7, there is a class identified by the variable `inp`. In the `WHERE` block, a condition is added that says that the `name` field of the `inp` node must be equal to a specific value (here `INPUT_VALUE` is the text of the input value). From the `MATCH` block, it is clear that `inp` is a node because of the parentheses, and it must be of type `Class`. It must be linked to another node *n* of type *Relationship*, which corresponds to an OWL ontology property. The link type is undefined in this case (the square brackets are empty), and the direction of the link is also undefined. So, the node could be linked as either `DOMAIN` or `RANGE`. In this case, there is no need to specify the direction of the link, because it is known that such links always come from a property to a class. We also know that this property must be linked to some class `x`. It is also given that the property linking these classes must have a relation to the sentence `rel_sent`. The condition `sent_super.name = "SentenceGroups"` guarantees that the `rel_sent` is a sentence. As a result, the query returns the value of `rel_sent.label` with the alias `context`, which is the sentence context.

```
MATCH (inp:Class)-[]-(n:Relationship),
    (n:Relationship)-[]-(x:Class),
    (n)-[:SPO]->(prop_type_1),
    (n)-[:SPO]->(rel_group),
    (rel_group)-[:SPO]->(rel_sent),
    (rel_sent)-[:SPO]-(sent_super)
WHERE
    inp.name = "INPUT_VALUE" and
    (prop_type_1.label = "object property" or
    prop_type_1.label = "action property" or
    prop_type_1.label = "action separately" or
    prop_type_1.label = "action level")
        and
    sent_super.name = "SentenceGroups"
RETURN DISTINCT x.label as result, rel_sent.label as context;
```

Listing 7: Cypher query to request the properties of an entity

Listing 7 also shows how to query the properties of an `INPUT_VALUE` entity contained in the ontology. To specify what the `INPUT_VALUE` is or could be an additional statement is added to the `MATCH` block: `(n)-[:SPO]->(prop_type_1)`. This specifies that the property `n` must be a child of `prop_type_1`. This is where the link direction is specified. In the `WHERE` block, sufficient values of the `label` field of `prop_type_1` are given. To make the query

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template more universal, since it is not known whether `INPUT_VALUE` is a noun or a verb, some options are given for the possible value of `prop_type_1.label`, combined with logical `or`. If the ontology has a semantic category hierarchy, the construction could be simplified as shown in Listing 8.

```
MATCH (inp:Class)-[]-(n:Relationship),
    (n:Relationship)-[]-(x:Class),
    (n)-[:SPO]->(prop_type_1),
    (n)-[:SPO]->(rel_group),
    (rel_group)-[:SPO]->(rel_sent),
    (rel_sent)-[:SPO]-(sent_super),
    (prop_type_1)-[:SPO]->(prop_type_category)
WHERE
    inp.name = "INPUT_VALUE" and
    prop_type_category.label = "entities properties"
        and
    sent_super.name = "SentenceGroups"
RETURN DISTINCT x.label as result, rel_sent.label as context;
```

Listing 8: Cypher query to retrieve the properties of an entity in case the ontology has a semantic category hierarchy

The result is the query field `label` of the `x` node. This will be the properties of an `inp` object. The contexts are also requested to recognise the conditions in which the property of the entity is mentioned. Similarly, actions of an object could be requested. For this purpose, it is only necessary to set another value for `prop_type_1.label` in the `WHERE` block, namely: `prop_type_1.label = object-action`.

If there are several possible options of relation in the query (`prop_type_1.label`), the result can contain its certain value, which then helps in answer synthesis. The next example (Listing 9) illustrates a query of object localisation without its type concretisation (Where is `INPUT_VALUE`?).

```
MATCH (inp:Class)-[]-(n:Relationship),
    (n:Relationship)-[]-(x:Class),
    (n)-[:SPO]->(prop_type_1),
    (n)-[:SPO]->(rel_group),
    (rel_group)-[:SPO]->(rel_sent),
    (rel_sent)-[:SPO]-(sent_super)
    (prop_type_1)-[:SPO]->(prop_type_category)
WHERE
    inp.label = "INPUT_VALUE" and
    prop_type_category.label = "localization" and
    sent_super.name = "SentenceGroups"
RETURN DISTINCT x.label as result, rel_sent.label as context,
    prop_type_1.label as predicate;

```

Listing 9: Request object localisation using Cypher query

The main peculiarity here is the statement `prop_type_1.label as predicate` in the `RETURN` block. This makes it return the specific semantic type of the obtained result.

In some cases, instead of predicates, lists of some entities (verbs, nouns, adjectives) can be included in a query. The peculiarity here is that the conditions are given for the node of

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the ontological graph linked to x. Thus, the requested object must not only be linked to some term x by the specific relationship, but this term must also be from a specific list. If the terms (or actions) are additionally classified in the ontology, the condition for the term will only be a descendant of a certain category.

Special mention should be made of modifier templates – fragments that can be added to the main query templates. Let us consider an example where the input parameter is not a single word, but a group of nouns. Therefore, there are related nouns and adjectives. To link to the input adjective concept, the relevant statements must be added as shown in Listing 10.

To the MATCH block:

```
    (inp:Class)-[]-(adj_plus:Relationship),
    (adj_plus:Relationship)-[]-(inp_adj_1:Class),
    (adj_plus)-[:SPO]->(rel_group)
```

and in the WHERE block:

```
        and
    inp_adj_1.label = "INPUT_VALUE_ADJ"
```

Listing 10: Parts of the Cypher query to be added for a link to the subject adjectives presence condition introduction

For the additional adjectives, add the same blocks but with further variables `inp_adj_2`, `inp_adj_3`, etc. It is also possible to add a condition of a noun in the indirect case by the statements shown in Listing 11.

To the MATCH block:

```
    (inp_noun_1:Class)-[]-(noun_plus:Relationship),
    (noun_plus)-[:SPO]->(rel_group)
```

and in the WHERE block:

```
        and
    inp_noun_1.label = "INPUT_VALUE_NOUN"
```

Listing 11: Parts of the Cypher query to be added for the condition of additional conditions expressed with nouns in indirect cases

In Listing 11, there is a condition for the presence of a noun in the same group where the main concept is included. However, conditions for the presence of adjectives related to this noun could also be added as shown in Listing 12.

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To the MATCH block:

```
    (inp_noun_1:Class)-[]-(adj_plus_add:Relationship),
    (adj_plus_add:Relationship)-[]-(inp_adj_add:Class),
    (adj_plus_add)-[:SPO]->(rel_group)
```

and in the WHERE block:

```
        and
    inp_adj_add.label = "INPUT_VALUE_ADJ_ADD"
```

Listing 12: Parts of the Cypher query to be added for the condition of adjectives related to nouns in indirect cases

In some cases, you may need to add a negation predicate to a query. To do this, you add a construction to the query as shown in Listing 13.

To the MATCH block:

```
    (neg:Class)-[]-(neg_rel:Relationship),
    (neg_rel)-[:SPO]->(rel_group)
```

and in the WHERE block:

```
        and
    (neg.label = "no" or
     neg.label = "not" or
     neg.label = "forbidden" or
     neg.label = "impossible" or
     neg.label = "cant" or
     neg.label = "unable")
```

Listing 13: Adding negation predicate condition parts to the Cypher query

5 SYNTHESIS OF NATURAL LANGUAGE RESPONSES BASED ON THE RESULTS OF FORMAL QUERY EXECUTION

The user interface of a dialogue system that simply displays the results of a formal query, even if it is beautifully designed, may not look very friendly, and sometimes may not even be completely understandable to a human. Therefore, the next important problem is the synthesis of natural language responses. Some principles of the approach of response generation based on information from the results of formal queries and the analysis of the source phrase using template instructions are described in our previous research (Litvin et al., 2020, 2021; Palagin et al., 2011; Palagin et al., 2020; V. Y. Velychko et al., 2014; V. Velychko et al., 2022).

In general, during the system development, the decision on how the response should appear in the user interface has to be balanced between providing ready-made contexts and text

synthesis. For example, to provide some tables, graphical objects, or other media to illustrate the response, the best option is to use ready-made contexts with links to the relevant files. In the current study, we omit methods for visualising and creating graphical and tabular materials (charts, graphs, diagrams) based on the results of queries in the user interface, although this approach is quite desirable in certain types of systems and, as demonstrated by Quamar, Lei et al. (2020), can be well implemented.

Contextual responses may be the best option when you need to provide detailed information. The synthesised responses provide better clarity for more specific questions where a formal answer is just a list of entities from the ontology. In this section we provide some examples of synthesised responses with instruction templates for some typical cases. These templates also provide user contexts (sentences) that explain and confirm the statement. In a software implementation, they are software entities (classes with methods) in the Python language that are attached to the system in a specific module file. Attempts have been made to add response templates in the form of XML descriptions, but this has resulted in increased complexity and reduced performance of the software.

Listing 14 shows the response template of a question about entity properties.

```
Repeat for each result:
    if INPUT_VALUE noun:
        INPUT_VALUE + може бути + result (fit the gender)
        + context
    is INPUT_VALUE verb:
        INPUT_VALUE + можна + result
        + context
```

Listing 14: The response template for the entity characteristic

The PyMorphy2 library methods (Litvin et al., 2020, 2021; Palagin et al., 2022) are used for determining the morphological characteristics of the word (part of speech, gender, case, etc.) and for word form matching. In the simple example in Listing 14, the part of speech of `INPUT_VALUE` must be checked. It can be a noun or a verb. If it is a noun, the `result` value must be gender-matched with `INPUT_VALUE`.

A more complicated example is shown in Listing 15. Here the subject of the query is object localisation. The particular localisation predicate is not specified in the input parameters of the query but appears in its results. As mentioned above, a certain semantic predicate could be used in a response synthesis.

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```
Repeat for each result:
    INPUT_VALUE + знаходиться +
        if predicate = "localization in set":
            + серед + result (plural, genitive case)
            + context
        if predicate = "localization near":
            + біля + result (genitive case)
            + context
        if predicate = "objective localization":
            + на + result (locative case)
            + context
        if predicate = " objective entering":
            + у + result (locative case)
            + context
        if predicate = "localization between objects":
            + між + result (plural, instrumental case)
            + context
        if predicate = "localization behind object":
            + за + result (instrumental case)
            + context
        if predicate = "localization in front of object":
            + перед + result (instrumental case)
            + context
        if predicate = "localization under object":
            + під + result (instrumental case)
            + context
        if predicate = "localization above object":
            + над + result (instrumental case)
            + context
        if predicate = "localization in object":
            + всередині + result (genitive case)
            + context
```

Listing 15: The entity localisation response generation template with tuning for different localisation types

From the example in Listing 15 we can see that a certain type of semantic predicate (in this case, localisation) determines the appropriate preposition and case for the value of the `result` variable for the Ukrainian language.

6 CONCLUSIONS AND FURTHER RESEARCH

A technique for the automatic generation of an OWL ontology from natural language text has been proposed. It is assumed that the language of the considered text is of the highly inflectional type. A feature of the method is that it does not require any previous tagging of the text, or a regular structure. The essence of the technique consists of a rule-based syntax-

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semantic analysis method and the fact that a large amount of semantic information in highly inflectional languages could be obtained by analysing the combinations of different parts of speech flections and prepositions. The ontology creation includes two stages: syntax-semantic analysis with intermediate creation of XML files, and ontology generation based on the corresponding OWL file. The proposed method was implemented as software and parameterised for the Ukrainian language. It was tested on real texts, which showed its efficiency. The created ontologies appear to be valid and can be processed by Protégé, RDFlib, and Neo4j (using the Neosemantics plugin). The ontologies appear to be deeply semantically structured and at the same time rather simple and regularly organised. Thus, the developed software system is a promising tool that can significantly and effectively automate the creation of graph databases using only plain text.

An approach and the corresponding software toolkit are developed for the creation of natural language dialogue systems based on the automatically built ontology for inflectional languages, in particular Ukrainian. An analysis technique is developed within the framework of the approach of an initial user phrase aimed at the formation of formal queries in the language Cypher. The essence of the method is a series of checks for the occurrence of certain words and/or word forms in the initial phrase. Depending on the set of check results, the main query template (or a group of such templates) is selected. Components from modifier templates are added to the main template (to its corresponding sections) as a result of additional checks, which make appropriate clarifications and extensions of the query. Query variables are supplemented with concepts obtained during the corresponding checks. Several queries (packages) can be created based on one initial phrase. An approach to the synthesis of natural language responses using query results and the values of source variables is also proposed. The unique feature of the approach is the use of specific values of semantic predicates obtained as a result of the query to the ontology, which allows the program to formulate the response more accurately and correctly by using appropriate prepositions and word forms. These response templates also provide instructions for matching word forms of concept results with the original concepts.

Based on the proposed approach, an experimental dialogue system was developed, which proved to be workable. It can become a prototype for the development of new more powerful dialogue styles able to be *learned* using natural language texts provided in the form of documents, or as search results obtained from the Internet. A further perspective of the system development is to allow it to create more detailed classified ontologies and expand the number of checks and variants of their results. Accordingly, a large number of basic and additional formal query templates and corresponding response synthesis templates can be created.

In a future study, our team plan to implement the ontology-related system as a part of the knowledge-oriented digital library of the smart-system for remote support of rehabilitation activities and services (Chaikovsky et al., 2023; Malakhov, 2022, 2023; Palagin et al., 2022). Further research will aim to develop original instruments and tools with the purpose of optimising user queries, and optimising usability for ontology-related systems.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Anna Litvin: Conceptualisation, Methodology, Writing – original draft preparation.

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Oleksandr Palagin: Project administration, Supervision, Conceptualisation, Methodology.

Kyrylo Malakhov: Software, Validation, Resources, Term, Writing – review & editing.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Research Article

Traffic control centre optimisation on South African freight corridors through intelligent weigh-in-motion

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ABSTRACT
High quality road infrastructure is essential to support economic growth for any region. For South Africa's landlocked economic hub 79% of goods are transported using roads infrastructure. Protection of the road infrastructure is implemented by means of overload control monitoring at traffic control centres (TCCs) on freight corridors. Statistics collected from TCC operations indicate that 75% to 85% of statically weighed vehicles are legally loaded, with the implication that unnecessary time was wasted for these vehicles. This paper therefore proposes an algorithm, called the intelligent weigh-in-motion (IWIM) algorithm, with the purpose to decrease static weighing of vehicles by implementing data sharing between TCCs on the freight corridor, combined with intelligent interpretation of this data. The selected algorithm was chosen after testing multiple artificial intelligence (AI) models (logistic regression, random forest tree, and artificial neural network) to achieve the best performance to decrease static weighing of vehicles while not increasing the number of overloaded vehicles allowed to proceed on the corridor. The best performing model to differentiate between overloaded and legal vehicles, random forest tree, achieved an average improvement of 65,83% in terms of vehicles to be statically weighed when compared to the current rule-based system employed at TCCs.

Keywords: Traffic control, overload control, freight corridor, intelligent weigh-in-motion

Categories: • **Applied computing** ∼ **Transportation**

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1 INTRODUCTION

South Africa is in dire need of expanding our exporting capability to support economic growth (Pedersen, 2007; Rodrigue, 2007; Turnbull, 2015). Most economic activities resulting in exports take place in landlocked regions, including Gauteng, which is the economic hub of the

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country and produces most manufactured goods. In a wider context, various countries within the Southern African Development Community (SADC) region, like Botswana, Zimbabwe, and Zambia, are landlocked and are therefore dependent on road and rail transport to facilitate supply chain operations (de Coning & Hoffman, 2014; Hoffman et al., 2013; Pricewaterhouse-Coopers, 2013). Declining rail infrastructure over the past decades will require extensive upgrading and revamping to become viable for large-scale transportation (Jorgensen, 2013; Marsay, 2013; Van der Mescht, 2006). Road transport is thus the predominant means for the region with 79% of delivery by road and 21% by rail (Jorgensen, 2013). The focus then turns to road transportation to deliver freight within the region.

Road transport is the dominant mode of land transport for export goods, including mining, agricultural, and manufactured goods. The quality of the national road network has a huge impact on the effectiveness of trade corridors that link areas of production with seaports. Road infrastructure (de Coning & Hoffman, 2014; Hoffman et al., 2013), border post operation (Bhero & Hoffman, 2013), and regional law enforcement efficiency are of utmost importance in the region's supply chains (Bosman & D'Angelo, 2011). Freight logistics within the South African context also have to take the SADC region into account. This is due to the fact that high volumes of cross-border freight are transported on multiple freight corridors to link the five landlocked countries in the region to seaports. The North-South corridor, terminating in Durban as a major seaport, spans in excess of 10 500 kilometre (km) with 18% of the corridor in South Africa (Odoki et al., 2009). Previous studies have specifically emphasised the importance of an efficient North-South corridor for the region (Odoki et al., 2009). Historic investment, annual maintenance, and upgrades have converted the South African road infrastructure into a 1 trillion South African Rand (ZAR) asset (Mitchell, 2013). This infrastructure is a catalyst to ensure commerce and economic growth in any region. It is thus of utmost importance to ensure the infrastructure is protected and legislation is implemented to achieve this protection.

1.1 Legislation

There are already mechanisms in place to ensure the protection of road infrastructure. This is achieved by a regulation from the government that states the maximum loading capacity of axles, a minimum driving axle, actual vehicle combination mass (AVCM) or gross vehicle mass (GVM), and load limits of tyres of a vehicle travelling on the road infrastructure (Department of Transport, 2004). The annual damage to the road network is estimated at ZAR 600 million (1997 value) (Department of Transport, 2004). The Council for Scientific and Industrial Research (CSIR) stated that ZAR 2 155 million is spent per annum on road construction and maintenance (CSIR, 1997). Taking the historic inflation into account over the years the annual damage is in excess of ZAR 1 500 million and the CSIR annual maintenance value is at over ZAR 5 500 million without taking into account the increase in heavy vehicle traffic on the roads of South Africa (Inflation.EU, 2016). This value is confirmed from SANRAL annual reports with maintenance cost stated as ZAR 6 276 million for the 2018/19 financial

year and ZAR 6 984 million for 2017/18 (SANRAL, 2019). This is an estimated cost of only repairing a road after the damage has taken place and does not consider the additional impact of poor road conditions on the quality of life of the general population in terms of life safety, vehicle maintenance cost increases, etc. The National Department of Transport (DOT) has stated in (Department of Transport, 2004): "It is, therefore, essential that effective law enforcement be carried out throughout South Africa in order to stop this economic sabotage and protect the country's most valuable asset - its road network".

Vehicle classification for the purpose of overload control is different for different end-user categories and regulations, therefore, referring to the specific vehicle type/configurations. Understanding the codes used to identify these categories is important for future data collection and interpretation. There are 17 classifications in this scheme, based on the 1998 revision, that range from motorcycles to long trucks. Trucks are classified under heavy vehicles that range from short trucks, two axle vehicles, to long eight or more-axle multi-trailer trucks (Mikros Systems, 1998; Smith & Visser, 2001). The legislation allows for a specific maximum permissible mass per vehicle type applicable for South African roads. To understand the importance of overload control the impact of overloaded vehicles on roads needs to be investigated.

1.2 Impact of overload control

From the above discussion, it is clear that road freight logistics is essential not only in South Africa but also in the SADC region. It is however a reality that profit margins in the logistics sectors are slim, and that competition is sometimes ruthless, which causes some transporters to overload their vehicles without considering the consequences on the road infrastructure. Overloading of vehicles occurs to leverage additional income on a trip without consideration of the damage it may cause to the road infrastructure. There is an extreme impact on other industries and the economy of a country if the road infrastructure is damaged, as the economy can come to a complete halt if the transport industry is no longer functional. It is therefore important to understand the damage that is caused by overloaded vehicles. It often happens that overloaded vehicles tend to travel the roads less travelled by making use of secondary roads. These roads are not designed to carry heavy vehicles and do not have concessionaires to regularly maintain them.

Studies have shown that 60% of road damage can be done by only 15 - 20% of vehicles being overloaded (CSIR, 1997). Furthermore, vehicles overloaded by 20% can decrease a road surface lifetime by more than 50%, as visually Figure 1 (Salama et al., 2006).

The need to protect the road infrastructure has however resulted in an overload control system that will statically reweigh legally loaded vehicles, that are loaded close to permissible limits, several times on the same corridor trip causing multiple delays (Hoffman & de Coning, 2014; SANRAL, 2017, 2018, 2019). Historical statistics have shown that a large number of vehicles (80% – 85%) are being weighed at static scales when legally loaded. This represents a significant negative impact on the economy, taking into account that around 1.7 to 1.8 million vehicles are statically weighed annually in South Africa (SANRAL, 2017, 2018, 2019).

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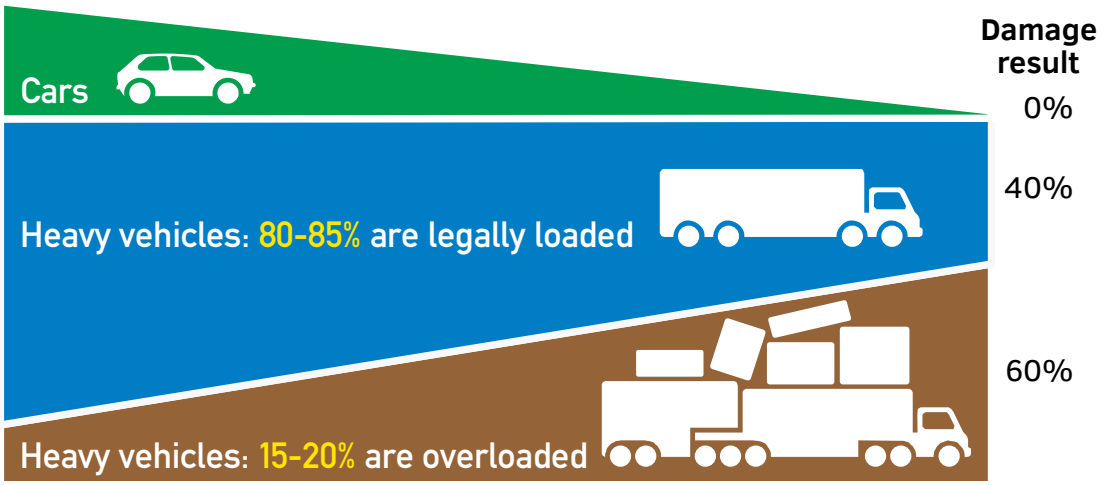

Figure 1: Road damage estimation due to overloading (CSIR, 1997)

Road surface damage is not the only impact overloaded vehicles will cause; it is however the easiest to observe. The operating cost of heavy vehicles tends to increase by 12.8% when vehicles operate on a deteriorated road infrastructure (Steyn & Haw, 2005). Overloaded vehicles operate outside the design specifications of vehicle manufacturers. These vehicles have an increased chance to be involved in accidents (Department of Transport, 2004). The annual cost due to road accidents has been estimated to be ZAR 142.95 billion which equates to 3.4% of South Africa's GDP (Labuschagne et al., 2017). The facts indicate that only 4.8% of accidents involve heavy vehicles, but unfortunately, these accidents cause a large number of fatalities when they do occur (MiWay, 2016; Stoltz, 2016). There is an extensive impact on the economy that includes police time, clearing the accident scene, lost work hours of workers stuck in traffic, and delayed delivery of goods (MiWay, 2016).

1.3 Traffic Control Centres

The enforcement of overload control rules is implemented at TCCs that are situated across the major freight corridors in South Africa. As an improvement of current TCC operations can only be done by investigating these operations, this section covers a case study of a TCC in South Africa.

Multiple TCCs are implemented across South Africa to ensure the protection of the road infrastructure. They are in most cases implemented on toll roads operated by different toll concessionaires servicing different national and regional roads. South African National Roads Agency SOC Ltd (SANRAL) has 13 TCCs that are operated by toll concessionaires and 16 satellite sites (SANRAL, 2017, 2018, 2019). The one big drawback in the design of the overload control network is that the different TCCs work in complete isolation from the TCCs up- or downstream on the same corridor (de Coning & Hoffman, 2016; Hoffman & de Coning, 2014;

Hoffman et al., 2013).

Investigation of the sites has identified certain inefficiencies or shortfalls within the current overload management, which negatively affects the operational cost and time delays experienced by legally loaded freight vehicles. From the perspective of considering the entire freight corridor as a single system, inefficiencies are apparent when taking into account that most vehicles travel past several TCCs on one journey. Vehicles are required to travel over a weigh-in-motion (WIM) scale and be directed to the static scale or corridor based on the weight observed at the WIM. Communication between isolated TCCs within the corridor context is absent, as there is no real-time data sharing between TCCs. Avoidable delays occur for legally loaded vehicles loaded close to the maximum loading capacity as such vehicles trigger the WIM threshold at several consecutive TCCs on their journey. This results in multiple static weighing of vehicles loaded close to the legal limit. It also leads to increased corruption levels due to increased contact time between truck drivers and potentially corrupt officials for vehicles that are overloaded. Potential overloaded vehicles are provided with the opportunity of skipping a queue at a TCC due to other legally loaded vehicles backing up onto the highway while being weighed. Some TCCs do not operate during night time, causing so-called fly-by-night companies to dispatch overloaded vehicles during these off-duty hours. Authorities have tried to counter some of these practices by providing traffic officials on duty with a specific daily quota of vehicles to be directed toward the static scale. In order to complete these quotas as early in the morning as possible, many traffic officials however apply the practice to also direct vehicles that did not trigger the WIM scale towards the static scale. The combined effect of these phenomena is a generally low level of efficiency of the overload control system.

The impact of the inefficient operations does not only affect the freight vehicle and TCC operation but also ripples through the entire supply chain, impacting all stakeholders including cargo owners, transport operators, truck drivers, road agencies, toll concessionaires, cross border agencies, port authorities, revenue services, cargo consignees and finally the consumer.

1.4 Artificial intelligence application

AI development has improved over the last few decades and has become a common occurrence without being obvious to the general public (De Raedt et al., 2016). Natural language processing is an example of the application of AI where a mobile phone can react to voice commands and understand the instructions to start phone calls, set reminders, or start navigation tools (Goldberg, 2017; Zhang et al., 2021). Backend analytics are used in large corporations like Facebook and Google to predict market trends or understand their users to implement target advertising (Zhang et al., 2021). AI implementations are used to improve cities and evolve them into smart cities or even develop self-driving cars (Liu et al., 2018; McClellan et al., 2018). Improving business operations is another typical application of AI that ranges from optimising warehouse flows or detecting water leaks within a water leak detection system (de Ponteves & Eremenko, 2018; de Coning & Mouton, 2020).

Within AI, machine learning is a mechanism to process large amounts of data, more than

what a human can process, in order to extract some knowledge to improve real-world and real-time decision-making (Campesato, 2020; Joshi, 2017; Raschka, 2016). Data gathering specifically for overload control can be implemented by means of WIM scales with the purpose of reducing vehicles required to be statically weighed (de Coning, 2022). TCCs that attempt to weigh all vehicles statically without making use of a WIM often cause extreme congestion resulting in vehicles that need to bypass the site (Shinohara et al., 2016). WIM scales are often used on a corridor to gather specific vehicle information that is relayed to law enforcement officials to take appropriate legal action (Capecci & Krupa, 2009; Green et al., 2002). Within the field overload control AI applications have been used to predict static scale weights by making use of previous TCC data to determine if the vehicle is within permissible limits (Bwire, 2019; de Coning, 2022). When a vehicle is predicted to be within limits it will not be subjected to mandatory checks at the TCC thus improving efficiency (Bwire, 2019). Performance testing of multiple AI models within the Waikato Environment for Knowledge Analysis (WEKA) had an 88% accuracy on predictions of a vehicle being overloaded or not overloaded (Bwire, 2019). This is however site-specific and all these applications indicate that an AI application can have significant benefits with implementation on the freight corridor as proposed in Section 2.4.

1.5 Problem statement

The problem is that the current overload control system in South Africa weighs an excess number of correctly loaded vehicles and this negatively impacts the whole supply chain. This article aims to address this problem by proposing an intelligent weigh-in-motion (IWIM) algorithm. This algorithm will be designed to have the ability to differentiate between legally and illegally loaded vehicles, in order to reduce the static weighing of vehicles that are legally loaded, while at the same time limiting the number of overloaded vehicles that are allowed to proceed on the corridor. This is achieved by optimising the accuracy of systems decision-making with minimal additional capital outlay and no TCC layout changes required. This approach is intended to reduce negative impacts on multiple stakeholders while still reliably protecting the road infrastructure.

The rest of the paper is structured as follows. Section 2 provides an overview of the case study that was used to optimise the current system being used at the TCC operations. This section also describes how the TCC data that was collected provides an accurate dataset representative of real-world behaviour. This data set will be used for the training and validation of the IWIM algorithm. Section 3 proposes an IWIM model to classify whether a vehicle is overloaded or not by making use of previously collected data on the corridor. Section 4 concludes the paper and discusses planned future work.

2 CASE STUDY TOWARDS OPTIMISING TCC OPERATIONS

A case study was conducted at the Mantsole and Heidelberg TCCs on the North-South corridor within South Africa to understand the operational flow of these sites. These TCCs were selected

as they directly follow each other on the N3-N1 corridor that links the port of Durban to Gauteng and to the Beitbridge border post, which is South Africa's busiest road border post for freight traffic. The operational flow of these individual TCCs is constructed to successfully direct vehicles loaded close to the legal threshold to the static scale. Most TCC designs include a screener lane with a WIM scale that directs a vehicle to the static scale if a weight threshold is triggered. This threshold for a WIM scale is typically 10% below the legal limit due to inaccuracies in the WIM scale. As the static scale has a higher accuracy only a static scale measurement can be legally used to prosecute a vehicle that is overloaded.

2.1 Status quo for overload control

The current TCCs are operated by multiple toll concessionaires, each of which has a public-private partnership (PPP) agreement with SANRAL. Each, however, has its own data management structure with the data sets isolated between TCCs as they are operated independently. Existing systems do not implement integrated overload control for an entire corridor but handle overload control on an isolated basis at each TCC. The normal rule that is applied at existing TCC systems is as follows: the axle configuration of the vehicle is first determined based on the consecutive sets of wheels passing the WIM scale. For each type of axle configuration, a specific threshold is applied; should this threshold be exceeded, the system will determine that the vehicle is potentially overloaded and should be weighed statically at a scale forming part of the same TCC. As a WIM scale is not as accurate as a static scale that has been correctly calibrated, the WIM scale measurement cannot be used for prosecution; furthermore, the expected error made by the WIM scale must be incorporated into the rule that is applied at the WIM scale, based on which it is decided whether to guide the vehicle to the static scale for a more accurate measurement. A vehicle is marked as overloaded if an axle weight, normalised against the permissible mass, is above 0.9 as indicated in Equation 1.

$$\text{Mark overloaded} = \text{Maximum (Axle loads)} > 0.90 \tag{1}$$

It is therefore possible that a vehicle that is within the legal weight limits will still trigger the WIM scale rule that will guide it to the static scale. Based on the result of the static weighing of the vehicle the owner of the vehicle may be prosecuted if it is found to be over the legally allowed weight limit for that axle configuration, and the vehicle may be impounded until its weight has been corrected. As many transporters load vehicles to very close to the legal weight limits, the situation currently exists where the majority of vehicles triggering the WIM scale rule are in fact not overweight and are therefore unnecessarily guided to the static scale. This tends to repeat itself at each weighbridge on the same corridor for the same vehicle, as each WIM scale will tend to produce the same result. These status quo (SQ) practices have the implication that the vehicle is subjected to many unnecessary static weighing actions.

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2.2 Industry data acquisition

Optimising freight corridor TCC operations requires analysis of the current data sources available. Multiple sources were collected that include traffic volumes, vehicle classification, WIM data, and static scale data on the South African freight corridors. Annual reports from SANRAL describe the statistics from TCCs across the country and clearly indicate that most vehicles that are statically weighed are within legal limits. SANRAL annual reports indicate this varies from 75% – 85%; this is the number that the proposed optimisation intends to decrease while ensuring overloaded vehicles are not sent to the corridor incorrectly (SANRAL, 2017, 2018, 2019).

An accurate representation of freight corridor activities can only be obtained by consolidating data from different industry sources. This consolidation will allow the construction of the inputs required by the algorithm with the goal of improving existing operations. Data sharing between TCCs, or "de-isolation", is a key requirement before the algorithm can be implemented in a real-world solution. The outcome of the algorithm will be to decide whether a vehicle could be overloaded since it was previously seen at an upstream TCC. The Mantsole and Heidelberg TCCs were selected to supply the input data. These TCCs are sequential sites on the North-South corridor. The SANRAL study included the North-South Corridor from Durban along the N3, merging with the N1 towards the Beitbridge border post. An overview of the corridor is indicated in Figure 2.

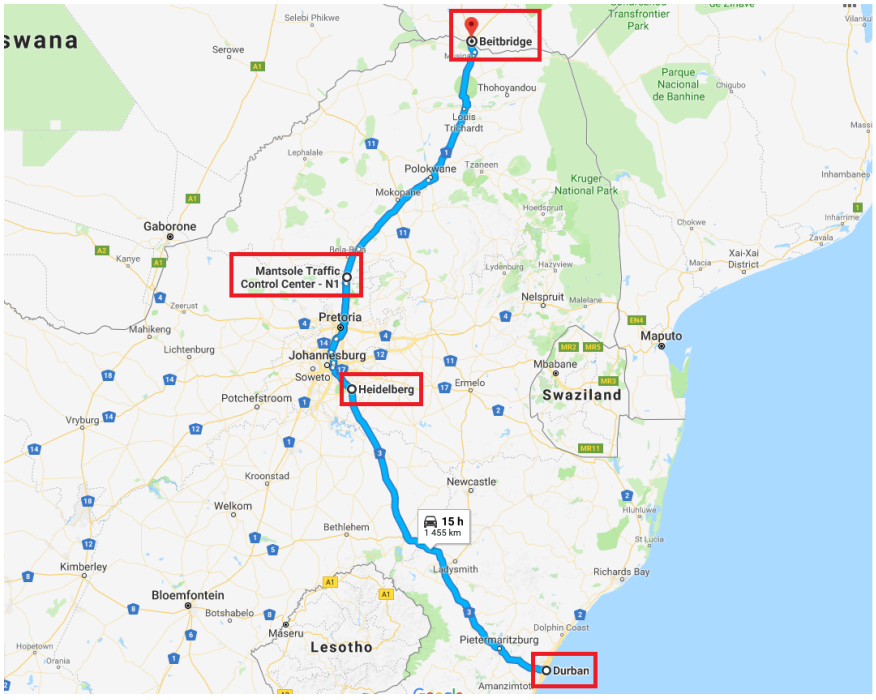

Figure 2: North-South corridor, from Durban to Beitbridge. [a]

[a]Map data © 2018 AfriGIS (Pty) Ltd, Google.

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The data time range and general statistics of the data sets are required to determine the overlap. The North-bound (NB) data sets for WIM and static scales at both the Mantsole and Heidelberg sites are firstly analysed. This is then followed by the same process for the South-bound (SB) WIM and static scale data at Heidelberg and Mantsole.

Data available for this time period were:

- Static scale data - Mantsole NB and SB
- Static scale data - Heidelberg NB and SB
- WIM scale data - Mantsole NB and SB
- WIM scale data - Heidelberg NB and SB

The NB data statistics are indicated in Table 1 with an overlap in data from *2021-04-01* to *2021-08-31* at both sites. Data provided from the WIM data set contained just below 482 000 vehicle weigh entries and just above 176 000 distinct vehicles in the time period. The static scale data had just above 80 000 vehicles statically weighed and just below 35 000 distinct vehicles. The WIM automated number plate recognition (ANPR) linking was unsuccessful with a *NAN* entry on just above 56 000 entries. This unsuccessful ANPR linking will ensure an accurate vehicle linking cannot be made and thus the current WIM scale data cannot be used with previous WIM scale data points to make a more informed decision.

Table 1: North-bound WIM and Static dataset statistics.

WIM	**Heidelberg**	**Mantsole**
Minimum date	2021-04-01 00:01:39	2021-04-01 00:00:04
Maximum date	2021-08-31 23:59:47	2021-08-31 23:56:31
Entry count	233392	248537
Distinct vehicle count	76469	99815
NAN values	45000	11032
Static	**Heidelberg**	**Mantsole**
Minimum date	2021-04-01 0:25	2021-04-01 00:15
Maximum date	2021-08-31 23:36	2021-08-31 23:49
Entry count	35322	44845
Distinct vehicle count	14456	20410

The SB data statistics are indicated in Table 2 with an overlap in data from *2021-03-01* to *2021-08-31* at both sites. The WIM data set contained just above 551 000 vehicle weigh entries and just above 153 000 distinct vehicles in the time period. The static scale data had

Table 2: South-bound WIM and Static dataset statistics.

WIM	**Mantsole**	**Heidelberg**
Minimum date	2021-03-01 00:07:32	2021-03-01 00:02:09
Maximum date	2021-08-31 23:54:44	2021-08-31 23:52:28
Entry count	279114	272572
Distinct vehicle count	82296	71187
NAN values	18238	51455

Static	**Mantsole**	**Heidelberg**
Minimum date	2021-03-01 00:20	2021-03-01 02:19
Maximum date	2021-08-31 23:54	2021-08-31 23:53
Entry count	37336	34585
Distinct vehicle count	17057	17449

just below 72 000 vehicles statically weighed and just above 34 000 distinct vehicles. The WIM ANPR linking was unsuccessful with a *NAN* entry on just below 70 000 entries.

The statistics of the overlapping data will give some additional insight into the traffic going past the TCC and what was directed to be statically weighed. The percentage of NB traffic directed to the static scale at Heidelberg was 15.13% and 18.04% at Mantsole. SB traffic had 13.38% directed to the static scale at Mantsole with 12.69% at Heidelberg. The next step in the process of constructing the input data set is to reliably link the data. This is essential and may be challenging when considering that WIM data sets had as much as 19.28% *NAN* or no registration information to be used for linking purposes.

2.2.1 Vehicle linking

Reliable linking of vehicle records is essential as previously discussed. Linked vehicles had to be correctly identified at both WIM and at both static scales for a given direction of travel: the WIM scale measurements are used as inputs for the decision algorithms, and the static scale measurements are required to determine the true outcomes for vehicles (overloaded or not) and the time differences between the WIM scales are used to determine if the previous sighting happened within the last 24 hours. The real-world data linking is thus a critical process step. The steps are firstly taken for the NB direction with a vehicle travelling between Heidelberg (as Site 1 NB) and Mantsole (as Site 2 NB). The SB direction will be for the reversal with vehicles travelling between Mantsole (as Site 1 SB) and Heidelberg (as Site 2 SB). Vehicle records for WIM and static scales are linked in the static scale data set and are used in the linking process. The process to link vehicle records for WIM and static scales is described as follows:

- Determine the vehicle registration number to be used as an identifier.

- Search the following site records for the same identifier.
- Determine the time variance between entries.
- Store values that have travelled between sites in the past 24 hours.

The values stored for the linking process are as follows for both Site 1 and Site 2:

- Vehicle identifier
- Date and time
- WIM axle configuration
- WIM axle count
- WIM axle unit weights
- WIM AVCM
- Travelling speed over WIM
- Static scale axle configuration
- Static scale axle count
- Static scale axle unit weights
- Static scale AVCM
- Static scale axle unit permissible weights
- Static scale permissible AVCM
- Overload status
- Site identifier

The linking process resulted in a total of 3 167 entries when combining NB and SB traffic. A total of 2 226 distinct vehicles were captured with the results in Table 3.

The linked data set had a total of 17 vehicles or 0.54% that were not overloaded at Site 1 and overloaded at Site 2. Another scenario was tested on 20 vehicles or 0.64% overloaded at Site 1 and not overloaded at Site 2. This will allow vehicles that corrected their loads at Site 1 to not be directed to the static scale at Site 2.

When training AI models on a data set where the observations with overloaded inputs or outcomes represent a small minority of the total training set, the training process tends to ignore the overloaded observations. By duplicating the small number of data points where

Table 3: Linked data set statistics.

North-bound	
Minimum date	2021-04-01 01:25:00
Maximum date	2021-08-31 09:54:00
South-bound	
Minimum date	2021-03-01 03:37:00
Maximum date	2021-08-31 17:55:00
Linked dataset	
Total NB and SB	3167
Distinct vehicle count	2266

vehicles were overloaded, we constructed an extended set that is called the padded data set. This allowed us to train the model on a more balanced data set where correct decision-making for both outcomes will be learned. This padded data set had 3692 data entries with an increase from 0.54% overloaded vehicles to 7.37% or from 17 vehicles to 272.

2.3 Rule-based performance

Any improvement against the current operations will first require an analysis of the SQ performance. The SQ rule-based system currently implemented determines whether a vehicle's WIM mass was potentially overloaded and whether it should be directed to the static scale. The WIM threshold is set at 10% from the maximum allowed mass or 90% of the legally permissible mass to determine if a vehicle will be directed to the static scale. This meant that a legally loaded vehicle that is loaded close to the permissible mass was directed to the static scale to determine its statically weighed load, even though it was not over the limit. The purpose of the AI model developed Section 2.4 is to decrease the number of legally loaded vehicles that are statically weighed.

Implementation of the rule-based system simply checked whether the maximum value for any axle and AVCM mass was above the threshold and mark it as overloaded. The steps were as follows:

- Determine the maximum of WIM axle masses and AVCM.
- Determine whether the load is more than 0.90 of the permissible mass.
- Direct to the static scale for mass above 0.90.
- Direct to the corridor for mass below 0.90.

The *first* rule-based performance was applied to the current site's WIM to determine the number of vehicles incorrectly directed to the static scale. The performance of the newly developed models was measured against this to determine whether it improved (reduced) the number of vehicles incorrectly sent to the static scale as indicated Equation 1.

The results of the rule-based performance testing implemented on the padded data set are shown in Figure 3 as a confusion matrix. YES indicates an overloaded vehicle and NO a non-overloaded vehicle. Rule-based 1 sent 91.39% of vehicles (3374 of 3692) incorrectly to the static scale (false positive).

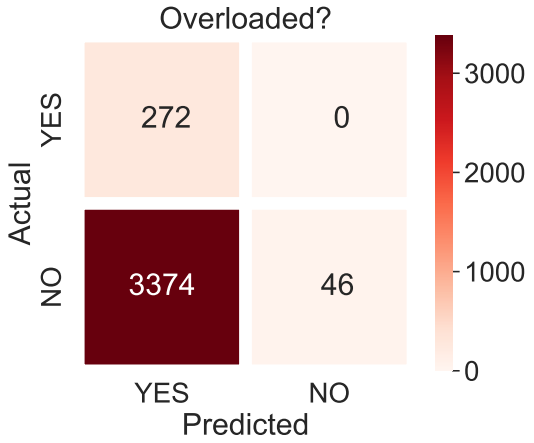

Figure 3: Confusion matrix results of the rule-based performance on the padded data set.

The *second* Rule-based model still used rule-based decision-making but had access to data that was shared between the TCCs. It, therefore, used WIM mass from the current and the previous TCC. The performance of the developed models will also be tested against this performance. The rule simply checked the maximum value in the measured data of both sites and marked a vehicle as overloaded if the value was above 0.90.

Another aspect to be tested was the impact of the adjusted threshold of the WIM. This added an additional dimension of testing to vehicles specifically not overloaded at Site 1 and increased the WIM threshold to a normalised axle and AVCM at Site 2. It was expected that the adjusted threshold would decrease the number of vehicles sent to the static scale. Achieving this would require data sharing between sites. The WIM thresholds were adjusted only for a non-overloaded state at Site 1 for this additional test. The current rule-based system is directed to the static scale vehicles within 10% of permissible mass or normalised weight above 0.90. The testing of the adjusted threshold was first to gradually increase the threshold to 1.00 from the current SQ threshold of 0.90. Additional testing was conducted by adjusting the threshold closer to the permissible mass as follows:

- Rule-based model 3: WIM weight threshold adjusted to normalised 0.95
- Rule-based model 4: WIM weight threshold adjusted to normalised 0.98

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- Rule-based model 5: WIM weight threshold adjusted to normalised 1.00

These thresholds were purely incremental increases to determine the improvement on the SQ performance but testing was also conducted on the data sets to determine the accuracy between the WIM and static scale. The linked values from all the WIM and static scales at Mantsole and Heidelberg in both NB and SB directions were individually analysed for the deviation between the WIM and the static scale. The average discrepancies in both directions were combined and Heidelberg had an average difference of 4.2%, where the WIM weight was lower than the static scale. Mantsole had an average of -5.41%, that is, the WIM weight was higher than the static scale. These two values were tested as additional rule-based scenarios as follows:

- Rule-based model 6: WIM weight threshold adjusted to normalised 1.0541
- Rule-based model 7: WIM weight threshold adjusted to normalised 0.958

The performance of the rule-based approaches is compared in Table 4. The results indicate an increase in accuracy as the threshold is adjusted but also an increase in vehicles incorrectly directed to the corridor. The confusion matrix results are displayed in terms of accuracy and the percentage of overloaded vehicles incorrectly sent to the corridor (false negative).

Table 4: Rule-based false-negative performance

	Accuracy	False negative
Rule-based 2	8,61%	0%
Rule-based 1	7,48%	0%
Rule-based 3	16,22%	11.76%
Rule-based 4	19,07%	35.29%
Rule-based 5	27,03%	35.29%
Rule-based 6	70,21%	70.59%
Rule-based 7	16,52%	11.76%

Accuracy is simply indicated as the sum of true positive and true negative, while the false negative performance was calculated as indicated in Equation 2 and false positive performance as indicated in Equation 3. The results in Table 4 show that the threshold adjustment alone would not adequately decrease the number of non-overloaded vehicles visiting the static scale and that an alternative approach is required.

$$\text{False negative performance} = \frac{\text{False negative count}}{\text{Total overloaded vehicles}} \tag{2}$$

$$\text{False positive performance} = \frac{\text{False positive count}}{\text{Total non overloaded vehicles}} \tag{3}$$

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2.4 Proposed IWIM solution

It is proposed to de-isolate the various TCCs by allowing information from one TCC to be used in conjunction with information from the following TCC on the corridor when a decision is made on whether to direct a vehicle to the static scale or not. The proposed IWIM concept will make the result of the static weighing of a vehicle available to all WIM scales on the same corridor, which will allow the control system at such WIM scales to make a more informed decision about whether to guide a vehicle to the associated static scale or not. This information link will allow any decision taken at a specific monitoring and control site to take into consideration the status of vehicles when detected at other TCCs prior to the respective monitoring event. The IWIM concept will implement a set of risk management rules before it decides whether to guide a vehicle that is detected at a WIM scale to the associated static scale. These rules will include the static weight of the vehicle as measured at a prior static scale, the time of travel between the prior static scale and the current WIM scale, the stopping of the vehicle between the respective scales, and the deviation of the vehicle from the normal route between the respective scales. Instead of basing the WIM decision only on the current WIM scale measurement, as is the case with the SQ rule-based method, the proposed new algorithm will incorporate the following information before a decision is made:

1. If the identified vehicle has not been weighed statically on the same corridor within a predetermined time period (which is based on the expected travel time on the corridor up to the position where the WIM scale is installed), the normal rule as explained above will apply - if the allowed threshold is exceeded the vehicle will be guided to the associated static scale.

2. If the identified vehicle has been weighed statically before on the same corridor and within the predetermined time period, it will be determined if the vehicle arrived at the current WIM scale within the normally expected travel time since the previous instance when the vehicle passed over either a WIM or static scale on the same corridor. If the vehicle significantly exceeded the normal travel time the normal rule will apply as above.

3. If the identified vehicle has been weighed statically before on the same corridor and it arrives within normal travel time, the static weighing record that has already been captured for that vehicle will be used to determine whether it should be guided to the associated static scale. If it was previously found to be within the legal limits it will be allowed to pass through, even though it may exceed the threshold as measured by the WIM scale. If it was however found to be over the legal limit at the previous static scale, it will be guided to the current static scale again, should it exceed the WIM scale threshold.

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2.5 Construction of an IWIM algorithm

The simplest method to implement the proposed IWIM concept would be to use a fixed set of rules to apply the logic of the decision-making process as described above. This however will require the determination of optimal threshold values for some of the decisions to be taken to distinguish between vehicles that should be guided to the static scale and vehicles that should be allowed to proceed on the corridor. The first element of uncertainty is the time that a vehicle, that was still legally loaded at the previous TCC, should be allowed to travel from the previous to the current TCC to still be regarded as low risk, given that vehicles do not always travel at the same speed. Another element of uncertainty is how close each axle weight, as determined by the last static scale, may be to the overload limit before the vehicle will be regarded as low risk, given that some load may have shifted during the trip, resulting in changes to the axle loads. A third element of uncertainty is the current WIM scale reading, which is known to be inaccurate. It is therefore not obvious when the current WIM reading should be used to override a previous static scale reading for the same vehicle.

Under such conditions of uncertainty, a rule-based classifier is known to suffer from some weaknesses when the input data has inherent noise (i.e. if the values are random in nature rather than fixed). The reason for this is the fact that a single input value with noise may cause the rule-based technique to branch off in the wrong direction, as a rule-based technique considers the various inputs one at a time. Other classification techniques, that process all input data in parallel, have been shown to have superior classification abilities when fed with noisy data, as the presence of noise in one input variable can to some extent be compensated for by the other inputs that influence the outcome (Boschetti & Massaron, 2015; Joshi, 2017).

The previous discussion provides the motivation to evaluate several different classification techniques to produce an accurate answer regarding the overloaded value of a vehicle detected at a WIM scale, using data from the current WIM scale as well as data from previous static scale measurements. By training such techniques on a specific data set and then testing them all on another unseen data set, it will be possible to determine with a high degree of certainty which of them will produce the most reliable classifications in a real-world scenario.

2.6 Dataset pre-processing

The de-isolation of the available information will require the system to send data to a central server to be converted into a standardised format to be distributed to the rest of the TCCs on the corridor. The data collected at the site needs to be described before a proposed algorithm can be developed. Data formatting between operators may be different but the same basic data is collected. Sequential TCC data will be described from the viewpoint of the second site, called *current* site or Site 2, making use of data from the *previous* site, Site 1, as input to classify whether a vehicle should be statically weighed or allowed to proceed on the corridor. The list below describes the data to be used as input into the IWIM algorithm that will be developed:

- Axle count

- Vehicle class
- Site 1 WIM axle weights for up to 15 vehicle axles (from statistics this was determined as the maximum axle count, and thus 15 was chosen as the number of axles to use)
- Site 1 AVCM as measured by WIM
- Site 1 static scale weights
- Site 1 AVCM static scale
- Site 2 WIM axle weights
- Site 2 AVCM WIM
- Normalised travel time between sites (actual travel time divided by average historical travel time)
- Overload status as determined by Site 1 static scale

In order to reliably train various classification techniques to produce the required outcome (identification of vehicles with a low risk of being overloaded) a relatively large training data set is required, as well as a separate test set. The industry data collection discussed in Section 2.2 combined with the vehicle linking between TCCs in Section 2.2.1 ensured the input variables are available for training and testing the model. The next step is the development of the IWIM algorithm by investigating the performance of multiple AI techniques performances to improve the current operations.

3 INTELLIGENT WEIGH-IN-MOTION DEVELOPMENT

The purpose of improving the overload control operations at the TCCs, by reducing the percentage of unnecessary static weighing of vehicles without increasing the risk of allowing overloaded vehicles on the road, requires an algorithm to facilitate this optimisation. This algorithm is going to be developed by making use of an AI model to be used as the IWIM model. The first step is to determine how AI-based classifiers may be applied to overload control.

3.1 Artificial intelligence model implementation

A classifier will be used to determine from input data whether a vehicle is overloaded or not overloaded and use this outcome in the decision-making process to decide if the vehicle must be statically weighed or not. A simplified explanation of how AI-based classifiers are trained is as follows:

- Each observation in the data set consists of a number of inputs (in this case the weight of each axle and AVCM at the previous static scale, the current WIM weight as well as the travel time from the previous static scale), as well as an output or target variable.
- The corresponding overloaded state of a vehicle is used as the output variable in each observation. During the training of the models, this output is used as a target variable, i.e. the ideal outcome that the classifier should produce when fed with input data.
- The total available data set is then divided into a training and test dataset using an 80/20 split, which is typical for such methods. This is essential, as it will allow the classifiers to be tested for their ability to generalise, i.e. to produce accurate answers for data not used during the training of the classifiers.
- Each classifier consists of a mathematical model that predicts the outcome from the inputs, with selectable parameters or weights of which the values can be changed to improve the classification accuracy.
- Training will now commence on the training dataset.
- This model is now ready to be tested on the testing dataset to see how accurate it truly is on unseen data.
- Accuracy of the model is set at a percentage accuracy, but a better metric is making use of the confusion matrix that will give four possible outcomes that provide better insight to the classification accuracy (Alwis, 2016):
  - Output 1 is the True Positive (TP) results where the output was set as overloaded and the model predicted the same.
  - Output 2 is the True Negative (TN) result where it was not overloaded, and the model predicted the same.
  - Output 3 is the False Positive (FP) where the model predicted it is overloaded but it was not overloaded.
  - Output 4 is the False Negative (FN) that will indicate the model incorrectly said the vehicle is not overloaded but it was overloaded.
- Accuracy will be the sum of Output 1 and 2 divided by the total size of the data set to reflect the model's performance.
- It is however important to use Output 3 and 4 to determine how many were incorrectly sent to the static scale (that will waste time, similar to the current system) or the corridor (allowing overloaded vehicles to continue travelling without being prosecuted).

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- It is also possible to assign different costs to the two types of errors (outputs 3 and 4 above) in cases where the risk of each type of error is not the same. E.g. in this case error output 3 will only cause some delay to a truck (a small risk or cost), while error output 4 will send an overloaded truck onto the corridor (a much larger risk or cost). In such a case the objective of the classifier is not to minimise the total error count but the total cost produced by these errors.

It was necessary to classify the binary outcome variable of *overloaded* as *output 1* or *not overloaded* as *output 0* from the input data set. The most suitable machine learning model to perform the classification had to be identified. Several classifier models were discussed for possible implementation. The following classifier models were considered for possible implementation (Raschka, 2016):

- k-nearest neighbour (kNN)
- Logistic regression
- Decision tree
- Random forest tree (RFT)
- Support vector machine (SVM)
- Naive Bayes classifiers
  - Gaussian
  - Multinomial
  - Bernoulli
- Artificial neural network (ANN)

kNN is known as a lazy classifier that memorises the training data set to predict a label classifier (Boschetti & Massaron, 2015; Shalev-Schwarts & Ben-David, 2014). Any new data is then fitted against the closest solution to predict the label outcome. This memorisation of the training set can suffer from overfitting and slight variations to the training set can have a drastic effect on the performance of the model.

Logistic regression is typically used to determine a target class output after training (Boschetti & Massaron, 2015). This is perfect to predict an outcome of 0 or 1 such as that required for the IWIM development (Raschka, 2016). Its disadvantage is that the classification does not converge if the classes are not perfectly linearly separable (Raschka, 2016).

Decision tree classification generates a tree-like structure with the data point determined by simple logic to produce the outcome (Raschka, 2016). A complex data set can be expected to have lower performance and this is addressed by combining several decision trees into an RFT.

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An RFT is an example of ensemble learning by combining several machine learning models together to increase performance (Boschetti & Massaron, 2015). Several decision trees are created by looking at a subset of the input variables. Each of the trees makes a decision and the majority decision is used as the output decision (Boschetti & Massaron, 2015; Joshi, 2017; Montantes, 2020; Raschka, 2016).

SVM is a machine learning model that can be used for classification or regression problems. SVM is however mostly used for tasks such as text classification, spam e-mail classification, sentiment analysis, or image recognition (Boschetti & Massaron, 2015; Raschka, 2016). The model can capture more complex relationships between data points but unfortunately is less effective on larger data sets, noisier data, and overlapping classes (Boschetti & Massaron, 2015; Raschka, 2016). This drawback means the model is not suitable for data sets from the industry.

Naive Bayes classifiers are probabilistic classifiers inspired by Bayes' theorem (Boschetti & Massaron, 2015). These models assume that all features are unrelated, even when there is a relationship between them (Joshi, 2017). The models are typically implemented on spam e-mail detection similar to the SVM. The naive Bayes classifiers available are the Gaussian, multinomial, and Bernoulli. The fact that these models assume variables are independent means they are not suitable for the current problem.

ANNs can be implemented for several purposes because they attempt to determine patterns in the data (Joshi, 2017; Shalev-Schwarts & Ben-David, 2014). ANNs take several repetitions/epochs to assign different weights to each variable to determine the appropriate outcome (Joshi, 2017). They can thus be used for several tasks, such as regression and classification (Joshi, 2017). The classification of the outcome for the current problem makes an ANN a suitable candidate but the computational power required is significantly higher than for other classifiers and training time may be increased as well.

Selecting the correct model to test on the data is based on several parameters, with a mix of technical and non-technical factors (Boehm et al., 2019). These do not just include accuracy but may include runtime, resource costs, and the ease of use of the tools (Boehm et al., 2019). The model selection for the IWIM has to result in a low number of overloaded vehicles being sent incorrectly to the corridor.

A preliminary test was conducted on the training techniques to determine their accuracy to further define which models could be used for formal training. The models with a low classification accuracy of – 80% or less – were eliminated as they tend to perform better with other applications. These included kNN, SVM, Gaussian, naive Bayes, multinomial naive Bayes, and Bernoulli naive Bayes. The performance of the logistic regression, RFT, and ANN classifiers was higher compared to the other models but logistic regression has a significantly lower performance compared to the RFT and ANN classifiers and is thus also excluded.

The RFT takes the input data set and constructs a tree to determine the output value. The first parameter to be adjusted was the maximum depth of the number of branches that would be generated for the tree. Several hyperparameters were tested by adjusting the n estimators, maximum depth, and minimum sample splits that served as input into the selection of the models to be implemented. The default value of the model was set to have a maximum of

100 depth constraints when building trees to determine possible outcomes. This was expected to increase the training time required to build the model. The second parameter set to be adjusted was the maximum depth the branches would generate, and it was set to 15. The third model had a maximum depth of 10 and the *n* estimator (the maximum number of trees generated in the forest) was set to 50, with the *n* estimator as the maximum number of trees generated in the forest. The RFT models tested were therefore as follows (de Coning, 2022):

1. Random forest tree 1: n estimators $= 100$
2. Random forest tree 2: maximum depth $= 15$
3. Random forest tree 3: maximum depth $= 10$, n estimators $= 50$

The ANN implementation uses a Python *Keras* classifier. First, the input layer was defined based on the 79 input variables obtained after preprocessing the data sets. Two hidden layers were added. The number of hidden layer nodes was selected as double the number of input nodes (i.e. 158 hidden nodes each); this is often used as a standard industry implementation and lowered the processing times (de Coning, 2022). It was established that increased hidden layer sizes did not influence the accuracy of the models. The dropout was varied between the data sets, with the batch sizes chosen as 25 (this size however did not influence the performance of the models during preliminary testing) because the size did not influence the performance of the models during preliminary testing.

Three ANN models were produced to test the data sets. Testing indicated that a large number of epochs did not change the results so 10 epochs were chosen for the models, while 100 epochs were used in preliminary testing. This lowered the processing times (de Coning, 2022).

1. ANN 1: 79 units on input layer, 158 units on hidden layers, *20% dropout applied*, Batch size of 25, 10 epochs.
2. ANN 2: 79 units on input layer, 158 units on hidden layers, *40% dropout applied*, Batch size of 25, 10 epochs.
3. ANN 3: 79 units on input layer, 158 units on hidden layers, *No dropout applied*, Batch size of 25, 10 epochs.

The model performance results will be investigated in more depth in the following section.

3.2 Results

The performance is firstly tested based on the improvement against the SQ. This is followed by the false negative and false positive percentage, and finally the accuracy. The models are trained on the padded data set and then tested on the original data sets as well as the padded data sets.

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The improvement is calculated by determining the percentage of vehicles that are correctly sent to the static scale versus the number of vehicles that are incorrectly sent to the static scale as depicted in Equation 4. These vehicles are legally loaded and sent to the static scale with the SQ rule-based implementation and the models are required to reduce these values. The improvement I is defined as follows:

$$I = (\text{Rule-based \% sent incorrectly to static scale}) - (\text{\% vehicle overloaded in the data set}) \quad (4)$$

Table 5 indicates the improvement for each of the models. Models are trained on the original and padded data sets to obtain the relevant improvement against all seven rule-based performances as discussed in Section 2.3. The ANN model's best performance purely based on improvement is ANN model 2 with a maximum improvement of 98.47% and an average of 86.33%. The RFT model with the best performance purely based on improvement is RFT 3 with a maximum improvement of 98.47% and an average of 86.64%. The highest accuracy was obtained with models that were trained with the padded data set with the ANN at 98.47% and the RFT with 98.47% improvement.

Table 5: Improvements on rule-based performance on the padded data set

	Max	Min	Average	Stdev
ANN 1	98.31%	64.73%	86.14%	10.87%
ANN 2	98.47%	64.95%	86.33%	10.85%
ANN 3	98.31%	64.84%	86.19%	10.83%
RFT 1	98.34%	65.57%	86.57%	10.60%
RFT 2	98.40%	65.57%	86.61%	10.62%
RFT 3	98.47%	65.57%	86.64%	10.64%

The model's maximum, minimum, average, and standard deviation are calculated for the initial assessment and indicated in Table 6. While ANN model 3 has the highest maximum accuracy at 98.92%, this model did not have the highest improvement of all the ANN models. While all RFT models had a maximum accuracy of 100%, RFT model 3 had the best improvement

False-negative and false-positive performance is a deciding factor specifically in the context of corridor optimisation. False-negative will send overloaded vehicles to the corridor which will damage the road surface. False-positive is similar to the current SQ performance that sends non-overloaded vehicles to the static scale. Improvement on this parameter will ensure optimisation of the entire corridor. False-negative and false-positive performances are indicated in Table 7. The RFT models had an average of 0.08% sent incorrectly to the corridor when tested on the original and padded data sets. The padded data set however indicated 0% sent incorrectly to the corridor which indicates no overloaded vehicles will be missed. RFT model 3 has the lowest average false-positive sending 0.26% incorrectly to the static scale.

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Table 6: Accuracy in padded data set

	Max	Min	Average	Stdev
ANN 1	98.69%	94.18%	96.14%	1.88%
ANN 2	98.75%	93.10%	95.10%	2.50%
ANN 3	98.92%	98.24%	98.59%	0.33%
RFT 1	100.00%	98.69%	99.63%	0.63%
RFT 2	100.00%	98.75%	99.65%	0.60%
RFT 3	100.00%	98.81%	99.66%	0.57%

This model trained on the padded data set however only sent 0.03% incorrectly to the static scale which is far lower than the current operations. This improvement however is highly dependent on a larger data set accurately linked. The performance training on the original data set was considerably lower when compared to the padded data set.

Table 7: False-negatives and false-positives in padded data set

	False Positive				**False Negative**			
	Max	Min	Average	Stdev	Max	Min	Average	Stdev
ANN 1	1.02%	0.81%	0.90%	0.09%	5.01%	0.29%	2.96%	1.97%
ANN 2	0.86%	0.41%	0.66%	0.19%	6.50%	0.38%	4.24%	2.66%
ANN 3	1.02%	0.68%	0.81%	0.15%	0.98%	0.16%	0.60%	0.39%
RFT 1	0.99%	0.00%	0.29%	0.47%	0.32%	0.00%	0.08%	0.16%
RFT 2	0.93%	0.00%	0.27%	0.44%	0.32%	0.00%	0.08%	0.16%
RFT 3	0.86%	0.00%	0.26%	0.41%	0.32%	0.00%	0.08%	0.16%

The RFT model 3 had the best performance as determined by the overview tables above. The next step is to confirm the model's performance by inspecting the confusion matrix of the model. Table 8 indicates the performance on the training, test, original, and padded data. A 100% accuracy is achieved on the training data set. The test data set had 1 vehicle sent incorrectly to the static scale with the padded data set with 1 vehicle sent incorrectly to the static scale. This model thus sent 0% of vehicles that were overloaded incorrectly to the corridor.

4 CONCLUSION AND FUTURE WORK

Freight logistics is important to support economic growth in a country like South Africa with economic hubs far from the coast, and a region like SADC which includes several landlocked

Table 8: Random forest tree classifier trained on the padded data set

	True Positive	True Negative	False Positive	False Negative	Total
Train	208	2745	0	0	2953
Test	64	674	1	0	739
Padded	272	3419	1	0	3692

countries. A deteriorating rail infrastructure ensures that road freight is the primary form of freight transportation. Overload control measures have been put in place to protect road infrastructure by implementing enforcement of legislation by means of TCCs. Unfortunately, there are inefficiencies in these operations as the system does not share information between TCCs, causing legally loaded vehicles to be subjected to several reweighs.

In this paper, we proposed a new overload control method to share data between sites to allow more intelligent decisions to be made by WIM scales. We furthermore demonstrated that this method can be combined with an AI-based classification model to improve the operational efficiency of the TCCs on the freight corridor. We constructed the dataset required by the AI model based on statistics extracted from measurements performed at the TCCs, combined with statistics from SANRAL's annual reports. The SANRAL reports also indicated that an average of 23.36% of statically weighed vehicles have been overloaded while only 0.18% are excessively overloaded to be arrested.

The proposed concept requires intelligent decision-making at TCCs, after the WIM measurement, to decide which vehicles need to be sent to the static scale. The available inputs include the weight measurements at the previous static scale and the local WIM scale as well as travel time from the previous TCC. As the data tends to be noisy, it is not trivial to make correct decisions, as indicated by the results achieved with the rule-based method. The best AI model sent no overloaded vehicles incorrectly to the corridor and 0.03% of non-overloaded vehicles incorrectly to the static scale. This is a huge decrease compared to the current 75 - 85% of legally loaded vehicles currently being directed to the static scale. This justifies the use of AI techniques to improve the quality of decision-making.

The results indicate that the proposed technique can significantly improve the SQ solution. We also demonstrated that AI techniques can improve upon the results achieved by a simple rule-based method. The current best solution will be to implement a random forest tree model. The expansion of additional sites for model training will give additional confidence in the system for future deployment.

Future work will be conducted to formally report on the costs and benefits for the different stakeholders involved. This can then be used as motivation for the country-wide implementation of the system. An expansion to the SADC region can be conducted after a successful proof of concept.

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Research Article

Digital transformation and post-Covid-19 education in South Africa: a review of literature

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ABSTRACT
Little thought or speculation was given to the possibilities of digital transformation for basic education until the global Covid-19 pandemic acted as a catalyst for digital transformation in education. Given the global trends toward digital transformation of teaching and learning, the South African basic education system has not been spared. While South African education policy was put in place to drive digital transformation, challenges persist in its implementation. The aim of this study was to examine the challenges that the South African basic education system faces in digital transformation and assess the strategies that can be used to mitigate these challenges. Although South Africa is attempting to address existing inequalities and the digital divide stemming from apartheid policies, the inequalities of the post-apartheid era have continued and worsened during the pandemic, resulting in a multi-layered digital divide that hinders quality and inclusive education. We adopted a narrative literature review in this study, focusing on previous studies that focused on ICT adoption, digital transformation, and inequality challenges in the South African education system. The findings make apparent the impact of the digital divide and former policies in perpetuating educational inequality. From the literature, strategies to mitigate the challenges are highlighted, including consultations.

Keywords: Digital divide, digital transformation, inclusive education, post-Covid-19 education

Categories: • *Applied Computing* ∼ *Education, e-Learning*

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1 INTRODUCTION AND BACKGROUND

The suspension of face-to-face learning through state-mandated closures due to the 2019 coronavirus disease (Covid-19) has led to a redefinition of teaching and learning approaches (Zhao & Watterston, 2021). The Covid-19 pandemic has clearly acted as a catalyst for digital

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transformation in education (UNICEF, 2020). In March 2020, approximately ninety percent of the global student population was affected by government-mandated school closures and other key sectors of the economy. The pandemic forced educational institutions to offer virtual teaching and learning as a substitute measure for national closures (Ofusori, 2021). The impact was worst in developing countries, as most failed to transition to digital teaching and learning. In South Africa, most schools suspended teaching and learning, except for privileged students attending well-equipped schools whose population is very insignificant. Major challenges in the country include poverty, lack of resources, cost of access, lack of technical skills among teachers and learners, lack of equipment to navigate the digital world, and poor or nonexistent networks. South Africa, like many other sub-Saharan African countries, has experienced economic problems since the turn of the millennium that have led to challenges in digital technology investment efforts, resulting in a serious digital technology deficit in the region (Letseka, 2016). In Zimbabwe, for example, the ratio of learners to computers was 1:32 in 2019. In addition, most of the prevailing traditional teaching and learning methods were already outdated, and the Covid-19 crisis has helped to disrupt this system and pave the way for the long overdue digital education system. Most institutions would have continued with traditional face-to-face instruction without plans to implement modern, technology-based instruction aligned with the global sustainable development goals (SDG). Although Covid-19 has proven to be a threat to human life, it has succeeded in pushing the boundaries of digital transformation. It has also highlighted the digital divide between developed and developing countries, rich and poor, in terms of quantity and quality of education received. From this literature, it can be inferred that the coronavirus pandemic has paved the way for the digital transformation of the education system, which is necessary to shape a future towards Society 5.0.

Digital transformation can be viewed as a process of technology adoption and acceptance that requires careful analysis of challenges and continuous engagement with them at each stage (Meyer & Gent, 2016). Like any other change, digital transformation can be voluntary or inevitable. The current Covid-19 pandemic made it inevitable for capable institutions to transform into the digital space to ensure academic continuity (David et al., 2020; Mhlanga & Moloi, 2020). Given the technological evolution and changes in industry, business and society, it is essential for education to evolve in a way that ensures its relevance. The digital transformation of education involves a shift from traditional pedagogy to more learner-centered, technology-driven learning with enhanced teaching and learning experiences (Osmundsen et al., 2018). It is important to keep in mind that education is a critical component of the United Nations Sustainable Development Goals (SDGs) and key to achieving many other SDGs. The goals of the SDGs are similar to those of Society 5.0, and the two reforms share a common direction in the vision of a new world. If people receive quality education, they can break out of the cycle of poverty, reduce inequalities, and achieve gender equality to create an inclusive society.

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1.1 Purpose of the study

The purpose of this study is to highlight the challenges of digital transformation in South African education and suggest strategies to remedy them. This paper explores approaches that can be used to guide education through blended learning methods that promote an inclusive education system. The inclusive basic education system has the potential to address learners' needs and equip them with the necessary skills and attributes to contribute positively to society, leading to the realisation of Society 5.0. The contribution of this study is to provide a universal framework for the driving factors that enable the transition to digital education. By promoting digital technologies in the education system, it is possible to create a society in which all people, regardless of gender, age, or disability, can lead fulfilling lives and fully develop their abilities. A combination of face-to-face and online instruction leads to high-quality teaching and learning experiences. All categories of learners - elite, middle class, and poor - should receive the same quantity and quality of education across the region. The likelihood of a return to what we used to call normal is uncertain. Therefore, we must work with the new norm and develop strategies that can improve the forms of learning used during the pandemic. Above all, promoting inclusive education ensures the achievement of global sustainable development goal number four (SDG4), which aims to ensure inclusive and impartial quality education and promote lifelong learning opportunities for all. Therefore, exploring strategies to improve education is an investment in the future development of the country.

1.2 Research question

This study reviews literature on the challenges faced by the South African education system as it strives for digital transformation, which has been accelerated by Covid-19 pandemic. It therefore answers the following research question:

> *"What are the digital transformation challenges facing the South African education system against the backdrop of Covid-19?"*

2 THEORETICAL FRAMEWORK

The study draws on the theory of the digital divide as a framework for the research. The digital divide theory assumes that there is an economic and social gap between a nation's population and its access to information and communication technologies (Pick & Sarkar, 2016). Digital transformation of education depends on individual adoption and acceptance of various educational technologies as well as access to and availability of appropriate resources. This paper is theoretically based on Van Dijk's digital divide theory (van Dijk, 2005). According to this theory, the main stages of the digital divide arise from the areas of economy, usability, and empowerment. Pick and Sarkar (2016) postulate that the digital divide is not just a lack of accessibility but goes beyond ICT access and considers the associated social and economic participation. Research proves that digital transformation can only be realised if appropriate

resources are available, and people are empowered with the required skills and knowledge to use the resources. While the South African government has put systems in place to address the provision of technological resources to schools, a lot still needs to be done to address other challenges of the digital divide. This makes it particularly appropriate to base this study on digital divide theory.

3 METHODOLOGY

Literature review involves the use of database searches to retrieve information that contributes to theoretical discussions of topics of interest. Narrative literature reviews provide readers with current information on a specific topic. Unlike systematic reviews, narrative reviews do not follow specific inclusion and exclusion evaluation criteria, nor restrict the search to selected databases. This study makes us of a narrative literature review to critically evaluate studies on digital transformation in South African education. This study focuses on the challenges, opportunities, and strategies to mitigate the challenges of digital transformation in the South African public education sector using secondary data sources. The review focused on identifying challenges encountered in the implementation of digital learning in primary and secondary education. Synthesis of the selected literature led to the generation of opportunities and mitigation strategies that can be used as a reference for digital transformation in education. The goal of the study is to provide readers with a descriptive overview of digital transformation in South African education.

3.1 Search and selection

The search criteria used to identify the literature was based on time frames, search terms, and search strategies. Recent literature from a variety of sources was used, without restricting to specific databases. Furthermore, both electronic and paper-based articles were used. This study therefore drew on published research and reports on the use of technology in South African schools. The goal was to find a set of articles that:

1. focus on the challenges of ICT adoption, implementation, or use by public schools in South Africa,
2. discuss educational inequality in South Africa, and
3. mention digital transformation in South African schools.

Publications focusing on the same aspects but in other countries were excluded. To ensure that the study reports on current issues, only recently published sources were used.

3.2 Literature analysis and synthesis

Analysis of the findings focused on summarising and analysing existing literature on digital transformation, including challenges, opportunities and coping strategies. Moreover, a critical view on the South African socio-economic status, and perspectives of educators, learners, and stakeholders on the use of technology in education was done. Attention has been given to government efforts and discourses around the implementation of the e-education policy of 2004 (DoE, 2004). The aim was to provide new insights that will contribute to policy making, future research and facilitating a conscious digital transformation in education to achieve an inclusive education system. A deductive approach was used to come up with strategies to mitigate the challenges, and hence facilitate digital transformation.

4 FINDINGS AND DISCUSSION

4.1 History of South African education

South Africa invests a significant amount of money in education (Macha & Kadakia, 2017). Macha and Kadakia (2017) also note that the country's education system has never fully recovered from the 1953 Bantu Education Act, which aimed to disenfranchise the country's majority black population from both the political and economic systems. The act deliberately aimed to turn blacks into subservient workers. It also systematically excluded black students from instruction in certain subjects. The effects of the discriminatory education system continue to this day, not least in terms of the quality of instruction provided by a generation of teachers who were themselves trained in an inferior system.

4.2 Transformation

It is widely recognised that in a future globalised world, traditionally valued skills and knowledge will become less important and a new set of skills will become more dominant and important (Hennessy et al., 2010; Pozo et al., 2021). Although the details vary, it is generally agreed that repetition, pattern prediction and recognition, memorisation, and all skills related to information gathering, storage, and retrieval will become less important due to artificial intelligence (AI) and related technologies (Damerji & Salimi, 2021; Ramlall, 2020). On the rise is a set of contemporary skills that include creativity, curiosity, critical thinking, entrepreneurship, collaboration, communication, growth mindset, global competence, and a variety of skills with different labels (Voogt et al., 2013; Zhao et al., 2021). For humans to succeed in the age of intelligent machines, they must not compete with the machines. Instead, they must become more human. Being unique and being endowed with social-emotional intelligence are distinct human qualities (Zhao, 2017) that machines do not (yet) have.

4.3 Challenges and mitigating strategies

The overall goal of education is to equip learners with knowledge and skills for the changing world that will enable them to contribute positively to society (UNICEF, 2021). South Africa has the potential to transform its education system and improve access to education for all citizens. The education system needs to be transformed to serve a new social order, meet pressing national needs, and respond to new realities and opportunities. However, this potential has not yet been fully realised due to existing challenges, which may be categorised into the three stages of digital divide, according to van Dijk's (2005) digital divide theory.

4.3.1 Economy

Inequality The main challenge facing the country's education system is to address past inequalities manifested by the former regime's discriminatory policies along racial lines. These challenges were exacerbated by the pandemic of the coronavirus, which promoted digital transformation through virtual teaching and learning. Nevertheless, the society driven by digital transformation has exposed many people, especially in sub-Saharan Africa, to another poverty called information poverty (Mascarenhas, 2010; Pick & Sarkar, 2016). The South African education system has been classified into several categories: geographic access, intellectual access, digital anxiety, skills access, and material access that promote or hinder inclusive and equitable education. Already marginalised teachers and learners have failed to adapt to new virtual learning and blended forms of education. South African learners, especially those from rural areas and disadvantaged families, are lagging in terms of knowledge acquisition.

Lack of resources To date, the South African education system is characterised by dingy schools with inadequate furniture, space, and equipment; high dropout rates; high teacher turnover; declining government financial support; and low efficiency and productivity of teaching and learning in schools (Adams et al., 2020; Meyer & Gent, 2016; South African Government, 2016). Some rural schools do not have power to support digital transformation and other technological devices, leaving traditional teaching and learning models as the only form of instruction in such contexts (Konyana & Konyana, 2013). Over the past decade, there has been a massive increase in the number of students due to rising birth rates and an influx of foreign immigrants, further straining already scarce human and material resources. These challenges have widened South Africa's digital transformation gap.

Although digital transformation has bridged the geographic gap between learners and educators, it has again widened the existing digital divide, leading to new barriers to the divide. These include gaps in the infrastructure for using digital technologies in education, particularly between rural and urban schools, which differentiate the privileged from the underprivileged. Other issues include lack of Internet access in poor communities, lack of technical skills among teachers and learners, lack of equipment to navigate the digital world, poor or nonexistent networks, and brain drain that strains the teaching profession. Unaffordable costs of establishing

adequate infrastructure, compounded by the lack of qualified technical support, pose a challenge to the education system.

4.3.2 Usability

Language issue According to Ofusori (2021), challenges that are often overlooked in the South African education system include the language barrier, as English dominates the digital space even though it is not the native language of the locals, which prevents both learners and teachers from effectively engaging in digital transformation that meets global standards. In addition, software applications are developed according to Western models and sometimes do not consider local cultural characteristics. In this regard, it is important for the government to develop digital content in local languages.

Technological shortcomings The main problem with the transition to the digital space in education is that the focus is on technological capabilities rather than on the needs of learners (Letseka, 2016). The potential of digital technology is caught between the growing pressure on the education system to socially transform society to meet South Africa's global standards and skill requirements, and the diverse academic conditions, large class sizes, pandemic of coronavirus, and multilingualism currently seen in these teaching and learning contexts (Zhao & Watterston, 2021). There are also misconceptions that view virtual learning as distance learning, rather than as a shift to the digital world, leading both teachers and learners to resist digital transformation.

4.3.3 Empowerment

Skills and knowledge shortage Teachers lack the skills and knowledge to address the diverse needs of students. Therefore, a framework should be established to equip teachers with the appropriate skills (Chataika et al., 2012). Teacher education programs are not keeping pace with technological advances, which leads to an imbalance in teaching and learning progress. Therefore, teacher education requirements need to be rethought to align with global development standards (Zhao & Watterston, 2021). The digital divide can best be mitigated by aligning human resource development and technical infrastructure to ensure that new technologies provide expanded, equitable access to improve educational opportunities for all, not just the technologically privileged (Jantjies, 2020; Sun et al., 2020; Tondeur et al., 2016).

Consultations Several commissions have been established to support and improve the integration of digital technologies in teaching and learning (United Nations, 2020). Therefore, the recommendations of these commissions need to be effectively implemented to be globally competitive. The South African government should encourage the use of free apps and educational websites, open educational resources, and the tremendous adoption of various educational technologies for distance learning.

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The current situation shows that South Africa will not be able to achieve Sustainable Development Goal 4 (SDG 4), which is to ensure inclusive and equitable quality education and lifelong learning opportunities for all by 2030. It is important to keep in mind that education is a critical component of the United Nations Sustainable Development Goals (SDGs) and key to achieving many other SDGs. From this literature, it can be argued that the South African education system needs to be carefully revised to achieve equitable and inclusive education that meets global standards. Strategies should be developed to mitigate challenges in the education system, some of which have been highlighted by the Covid-19 pandemic.

Overall, there is need for a social justice approach to education that will help addressing segregation practices that exist within the system. The education design strategies should aim to disrupt the existing hegemonic worldviews that do not consider the diversity of circumstances of learners in South Africa and allow all students to match their individual ways of learning to varied approaches of engagement, expression of learning and intellectual representation.

4.4 Recommendations

While there is still a need to help students develop basic practical skills, education should also be about developing the humanity of citizens in local, national, and global societies. Zhao and Watterston (2021) agree with this when they recognise the rise of education through contemporary skills such as creativity, global competence, and critical thinking. Education must be seen as a pathway to lifelong learning, satisfaction, happiness, well-being, opportunity, and contribution to humanity.

For the post Covid-19 era, curricula must be developed to meet the needs of students by helping them develop the new skills of creativity, curiosity, critical thinking, entrepreneurship, collaboration, communication, and growth mindset. In addition, it is imperative that the curriculum focuses on teaching students' creativity, entrepreneurial thinking, and global competency to succeed in the age of smart machines and globalisation.

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Research Article

Integrating technology in teaching and learning practices: students' competencies

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ABSTRACT
Technology usage in teaching and learning is not a new pedagogical practice and the benefits of its adoption are noted in the literature. However, an area that is often neglected when integrating technology into teaching and learning is the competency level of the would-be learners or students. This study investigated student competency levels based on factors such as their prior exposure to computers and the availability of facilitating conditions such as human or technical support. The study adopted a descriptive approach and was quantitative in nature. Data was collected from 368 students by means of a questionnaire. Descriptive statistics were obtained through quantitative analysis and the computer-based assessment acceptance model (CBAAM) was adopted. The results showed that the provisioning of facilitating conditions in a technology-integrated academic environment positively influences student competency in the use of technology. Furthermore, results showed that prior exposure to computers significantly impacts student competency levels in such an environment.

Keywords: teaching and learning practices, technology integration, student competency

Categories: • *Applied Computing* ∼ *Education, e-Learning*

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1 INTRODUCTION

The need to enhance teaching and learning efficiency has led to the emergence and adoption of different technological innovations. One such innovation is the Programmed Logic for Automated Teaching Operations (PLATO) developed at the University of Illinois. The PLATO project aimed to assist teachers to design and deliver module material. In 1974, the International Business Machine (IBM) Research Center also developed a computer program that is capable of teaching linguistic and scientific modules (Garrison, 2011). These innovations sparked interest in the use of technology in education and it has now become a global trend (Garrison, 2011).

In recent years, technology's interactive and dynamic offerings have changed the face of teaching and learning (Faloye et al., 2020; Garrison, 2011). Pedagogical practices have in-

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corporated various technological approaches (Faloye & Ajayi, 2021). Higher education institutions have introduced online registration, e-learning, blended learning and podcasting, etc. (Timotheou & Hennessy, 2021). E-learning enables online delivery of lectures and study material (Adikwu et al., 2017), facilitates communication between teachers and students and enables the latter to submit their work online (Naik et al., 2020). Several studies have shown that effective use of ICT enhances student learning at tertiary level (Faniran et al., 2020; Khlaif & Salha, 2022; Ramaila & Molwele, 2022). It supports interactive instruction and allows for bi-directional pedagogical activities. Teaching and learning can occur any time, any place in a collaborative and interactive manner (Ramaila & Molwele, 2022). The primary function of technology integration in educational institutions is its capacity for interactive learning through discussion, sharing and delivery of module material, communication, and multimedia (Mohebi, 2021). This led to many developed countries adopting technology for pedagogical purposes, with developing countries, including South Africa, now following suit. Indeed, technological innovations are now widespread across all levels of the education system, especially in higher education (Siddiqui et al., 2020).

While South African universities are embracing technology on an on-going basis, the challenge lies in the fact that many students lack competence to make the most of technological tools. The root cause is disadvantaged students' lack of exposure prior to entering university. Economic disparities have resulted in a marked digital divide, with most South African households unable to afford technological infrastructure (Jantjies, 2020; Makhado & Tshisikhawe, 2021). In some instances, the first time a student operates a computer is on gaining access to the university's local area network (Faloye et al., 2020). While universities have adopted numerous strategies to accommodate these 'digital immigrants', most involve a one-size-fits-all approach which is often inadequate to address individual students' challenges.

It is against this background that this study's research question was determined: What factors affect students' computer self-efficacy (or lack of), prior to joining the university? This study investigated student competency levels in the use of learning technologies and the causes of low competency levels. The following sections present a literature review, discuss the methodology employed, and present and discuss the study's results. This is followed by a conclusion and recommendations.

2 LITERATURE REVIEW

Technological integration in educational institutions has been defined differently by different authors (Khlaif & Salha, 2022; Yilmaz, 2021). However, the definitions all revolve around the use of technological tools for pedagogical purposes.

Technology integration has gained traction in educational institutions due to its numerous advantages. Studies show that the use of technology for teaching and learning activities teaches students' basic computer skills (Tanik Önal, 2021; Wang, 2021; West & Malatji, 2021). The ability to create and manipulate data improves their chances of finding a job. However, Njiku et al. (2019) noted that that some academic institutions are reluctant to change their

teaching and learning approach due to a lack of infrastructure and awareness. For instance, the systems currently used to assess student performance in some universities are still based on traditional methods instead of more modern computer-based assessment (CBA), which involves online assessment. Technology-enhanced environments offer a better platform for learning than traditional learning environments and are a more effective way of teaching, learning and assessment. However, students that are not familiar with the use of technology could be at a disadvantage when it comes to CBA (Tosuntaş et al., 2019).

It has also been observed that the use of technology in the classroom saves time as teachers can upload module material online, especially when there are many students in a class (Dexter & Richardson, 2019). It can also be harnessed for one-on-one teaching of students who are lagging behind and lecturers can post additional material on learning sites such as Moodle to enhance students' understanding. Furthermore, Ankiewicz (2020) observed that technology enables teachers to cater to students' diverse needs. This is important as students come from different academic backgrounds and have different learning styles and approaches.

Chisango and Marongwe (2021) also found that, through self-directed learning, students develop confidence and are empowered to take decisions relating to their studies. Similarly, Backfisch et al. (2021) found that students enjoy using technology, especially to search for information and to carry out learning tasks, and that the technology usage develops the digital skills students need for the workplace and to participate in the digital world. Furthermore, around 78% of the students that participated in Jones and Bridges' (2016) study reported that the use of computer-based writing tools such as Grammarly and Hemingway Editor enhanced their writing skills.

Bereczki and Kárpáti (2021) conducted a study that incorporated web-based programs in Mathematics courses at the Massachusetts Institute of Technology and found that student performance improved. They concluded that technology boosts student performance in science subjects. Furthermore, the use of technology promotes self-directed learning (SDL), with students assuming primary responsibility for learning activities such as planning, implementing ideas, and evaluation of their efforts without educators' assistance (Bernacki et al., 2020; Ratheeswari, 2018).

However, Sarker et al. (2019) cautioned that educational technologies are not "magic tools" to boost students' academic performance. They highlighted the need to investigate the actual use of the technologies integrated into educational systems as students might use them for leisure or personal use rather than academic activities, with negative effects on their academic performance. Hanshaw et al. (2022) concurred and added that students tend to focus on chatting and visiting social networks. Tanik Önal (2021) conducted a survey to identify the activities that students engage in using technological devices. Around 60% of the respondents indicated that most of their time was spent "engaging in leisure activities" particularly on social networks and on financial websites (e.g., forex). Studies have found that spending an excessive amount of time on the Internet can cause psychological distress such as anxiety, insomnia, social seclusion and depression which in turn negatively affects academic achievement (Banoğlu & Gümüş, 2022; Kroesch et al., 2022).

Hanshaw et al. (2022) found that the amount of time students devote to academic work while using a computer and the Internet varies. They concluded that the total amount of time an individual devotes to the use of technology is a function of their motives for such use. According to Faloye and Ajayi (2021), some students devote less than 10% of their total time on the Internet to academic work, with 90% spent on personal tasks, leisure and entertainment. Hanshaw et al. (2022) reported that students spend a total of 19 hours per week on computer, of which around five was spent on academic work. It can thus be concluded that technology integration does not guarantee improved academic performance especially if time meant for study is spent on non-academic online activities. However, if technology is utilised appropriately by students, it will enhance teaching and learning efficiency and better academic performance will be achieved.

3 METHODOLOGY

A descriptive design approach was implemented to achieve the objective of this study. A descriptive design seeks to describe the characteristics of an observed phenomenon (Bhattacherjee, 2012). The primary aim of a descriptive study is to give a detailed description of the crucial factors surrounding the phenomenon of interest. In the context of this study, the descriptive design offered the researchers clear insight into the factors that contribute towards students' competencies in the use of educational technology.

The target population for this study was first year university students of a higher educational institution in South Africa, with a total population of around 9,000 students. First year students were selected as the literature showed that the impact of digital exclusion is most evident among this grouping. In addition, a pilot study conducted earlier in the study found that this cohort of students struggles to use technologies, particularly those from disadvantaged backgrounds.

This study employed probability sampling techniques because it helps in eliminating sampling bias by giving every student in the target population an equal chance of being selected (Bhattacherjee, 2012). More specifically, a cluster probability sampling technique and a simple random sampling technique were applied in this study. After the clusters were identified and gathered, a sample was drawn from each cluster by using the simple random sampling method. In accordance with Krejcie and Morgan's (1970) sampling table, the sample required was approximately 368. Thus, the combination of all the drawn samples (368 in total) constituted the final sample for the study.

Since this was a quantitative study, data was collected by means of a semi-structured questionnaire. In this study, self-administered questionnaires were given out by hand to the respondents. Before the questionnaires were given out, questionnaire pre-testing was carried out to assess the quality of the questions in the questionnaires.

The first page of the questionnaire described the aim of the research and set out the instructions, and the researchers' contact details. The questionnaire contained 40 questions and employed a five-point Likert scale. The questions were divided into 10 sections. Section A

contained questions on the participants' demographic details, including age, gender, ethnicity, and qualifications. The remainder of the sections contained questions based on the study's constructs. Participants were requested to read the instructions and complete the questionnaire which typically required 10-15 minutes of their time. The data was captured using Microsoft Excel and exported to the Statistical Package for the Social Sciences (SPSS) for cleaning and analysis.

4 CONCEPTUAL FRAMEWORK

This study revolved around the use of educational technologies. However, student achievement after capitalising on technologies depends on certain factors. Table 1 sets out theories that predict acceptance and use of technologies that were used in previous studies. None of these models offers sufficient constructs and variables to investigate student computer self-efficacy. For instance, higher education institutions require students to use learning management systems, computers, the Internet and other technological resources; therefore, investigating their skills in this regard is crucial. Hence, researchers have developed conceptual models that combine constructs and variables from other information systems models. Alki (2020) extended the Technology Acceptance Model (TAM) (Marangunić & Granić, 2015) by adding computer anxiety and computer attitude to investigate students' acceptance of computer-based assessment (CBA).

Table 1: Technology acceptance theories.

	Model	Constructs	Description
Sarver (1983)	Theory of reasoned action	- Attitude - Subject norms	The theory posits that individual behaviour is a function of behavioural intentions that are, in turn, a function of attitudes and subjective norms.
Ajzen (1991)	Theory of planned behaviour	- Attitude - Subject norms - Perceived behavioural control	The theory of planned behaviour is an extension of the theory of reasoned action. The theory posits that an individual's behaviour is driven by behaviour intentions, where behaviour intentions are a function of three determinants: an individual's attitude toward behaviour, subjective norms and perceived behavioural control.

Continued on next page

Table 1 – *continued from previous page*

	Model	Constructs	Description
Marangunić and Granić (2015)	Technology Acceptance Model	- Perceived usefulness - Perceived ease of use	The Technology Acceptance Model (TAM) is an information systems theory that models how users come to accept and use a technology.
Murray (2009)	Diffusion of innovation theory	- Relative advantage - Compatibility - Trialability - Observability - Complexity	Diffusion research revolves around the conditions which increase or decrease the likelihood that members of a given social system will adopt a new idea, product, or practice.
Chang (2012)	Unified theory of acceptance and use of technology (UTAUT)	- Performance expectancy - Effort expectancy - The ease of use - Social factors - Facilitating conditions - Attitude - Behavioural intentions	The unified theory of acceptance and use of technology model aims to explain user intentions to use an information system and subsequent usage behaviour.

Following an extensive review of the literature, the Computer Based Assessment Acceptance Model (CBAAM) developed by Terzis and Economides (2011) was employed for this study. It was selected because it contains constructs that were deemed relevant in investigating the technological skills required to use available technological resources. The CBAAM was based on three models of technology adoption and usage, namely, the Technology Acceptance Model (TAM), unified theory of acceptance and use of technology (UTAUT) and the theory of planned behaviour (TPB). Seven constructs were derived from these three models, namely, social influence; facilitating conditions; computer self-efficacy; perceived ease-of-use; perceived usefulness; perceived playfulness and behavioural intention. Terzis and Economides (2011) added two constructs known as goal expectancy and content to form the CBAAM causal model to explain the constructs that affect the intention to use computer-based assessment. Thus, as shown in Figure 1, the CBAAM model has nine constructs.

This study is focused on the facilitating conditions (FC) and computer self-efficacy (CSE) constructs of the CBAAM model as important factors influencing perceived ease-of-use and ultimately intention to use computer-based assessment. The data captured through the questionnaire forms part of a larger study that considers more of the constructs of the CBAAM model, but these are not discussed in this paper.

Facilitating conditions (FCs) refer to the conditions that a user believes are available to enhance their use of technology (Terzis & Economides, 2011). In the context of this study, this construct was employed to investigate if students felt that the necessary resources and support (staff or technical) were available to them when using technological resources.

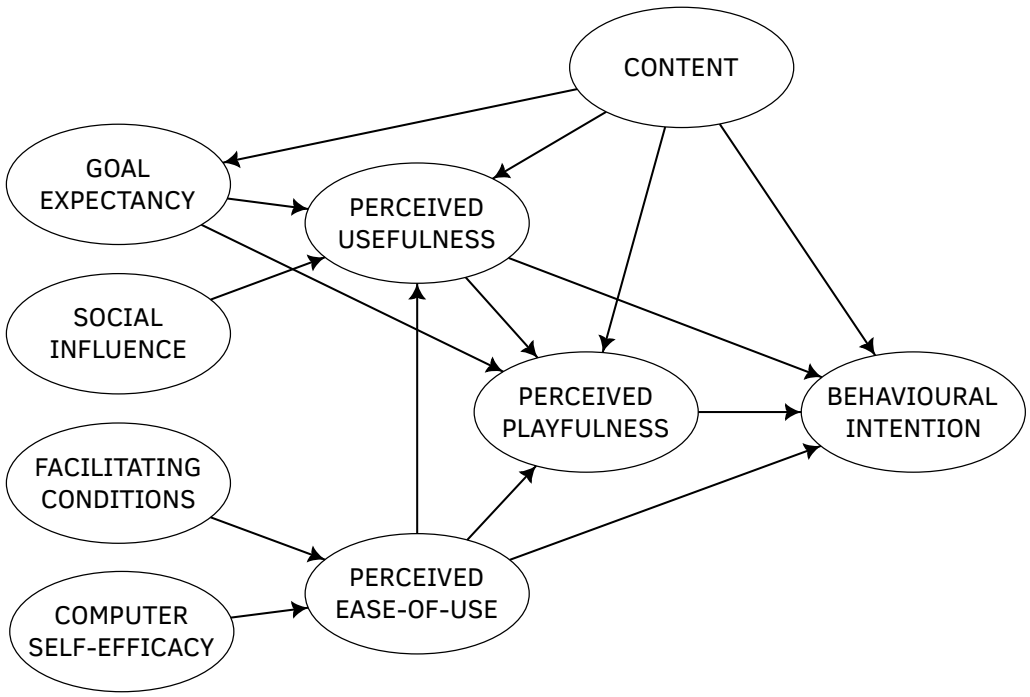

Figure 1: The CBAAM causal model[a]

[a](Terzis & Economides, 2011, p. 1034)

Computer self-efficacy (CSE) measures how an individual perceives their capabilities and competencies with regard to the efficient use of computers (Compeau et al., 1999). In the context of this study, it was used to examine if students felt that they could use computers as well as other computing devices on their own or with assistance.

5 ANALYSIS AND DISCUSSION

Inferential and descriptive analysis were employed to generate statistics and make informed inferences. The Cronbach alpha test was used to check the questionnaire's data (the questions) for internal consistency and reliability. For a questionnaire's data to be considered reliable, the reliability coefficient (Cronbach alpha) based on the inter-item relationship (between all the questions) must be greater than 0.7 (Bhattacherjee, 2012). The most important items in the questionnaire that are relevant to this paper are the five items (questions) under the facilitating conditions construct and the six (6) items (questions) under the computer self-efficacy construct. As shown in Table 2, the reliability coefficient obtained among the 5 facilitating condition questions (items) was 0.877 ($>$ 0.7) while the reliability coefficient among the 6 computer self-efficacy questions (items) was 0.824 ($>$ 0.7), thereby confirming

Table 2: Scale reliability

Constructs	Cronbach's alpha	Number of items
Facilitating conditions	0.877	5
Computer self-efficacy	0.824	6

the reliability of the questionnaire data used in this study.

Based on a normality test conducted on the questionnaire data, the data gathered from all the questionnaires were not normally distributed; therefore, a chi-squared (non-parametric) test was used to ascertain whether there was a significant relationship between the variables investigated. In a chi-squared test, a p-value greater than 0.05 indicates no significant relationship between the variables under consideration, while one of less than 0.05 points to a significant relationship.

Computer self-efficacy was determined by measuring student competence in the use of computers, while facilitating conditions were all conditions that supported students to use e-learning platforms. Computer self-efficacy was used to gain insights into students' computer skills, and competence levels with regards to the e-learning platform. Facilitating conditions were used to determine whether students had the resources required to use these platforms. We considered computers as they are the most common devices used by students to conduct learning tasks. In addition, most e-learning platforms such as Moodle are accessed through desktops or personal computers due to their large screen sizes.

As shown in Figure 2, more than half the participants (N = 368) demonstrated high proficiency in the use of the e-learning platform (Learn) provided by the institution. This could be attributed to their exposure to computers prior to entering university (see Figure 3). According to Compeau et al. (2015), access to computers before entering university brings about strong affinity and confidence among students, which in turn leads to high competency levels. Technologies such as computers, the Internet and Blackboard have become an integral component of classrooms from primary to tertiary level (Timotheou & Hennessy, 2021). This has resulted in students developing technological skills from an early age. Furthermore, due to the pervasiveness of mobile technologies, many students are exposed to sophisticated technologies prior to entering university and thus develop the skills required to use them.

A few participants demonstrated low competency in the use of computers. These students were unable to perform several learning tasks on a computer. Further observation revealed that this group of students was only exposed to technologies in their first year at university. This is in line with previous studies that found that prior access to technology impacts students' computer self-efficacy (Ankiewicz, 2020; Faloye & Ajayi, 2021). Young adults tend to develop an affinity with technology through continuous usage which, in turn, increases their competency level.

As shown in Figure 4, most of the students stated that they were competent in the use of computers. Also, a significant percentage of participants who had access to a computer

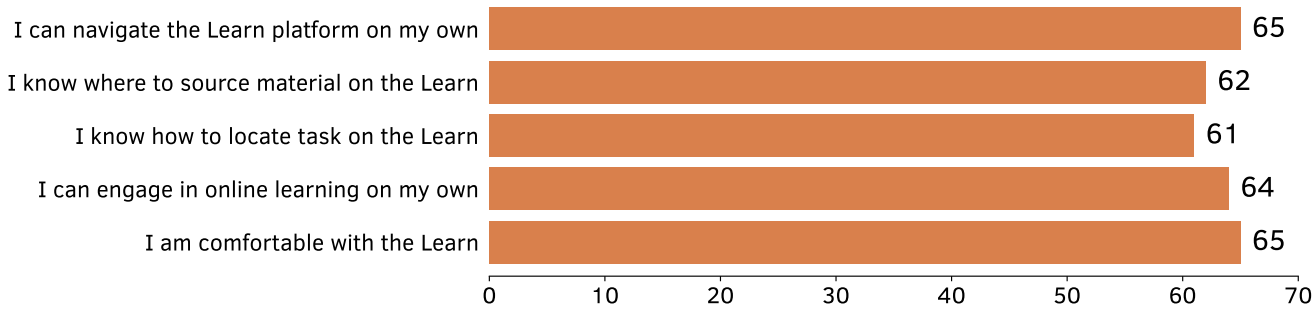

Figure 2: Student competency level with the e-learning platform (Learn)

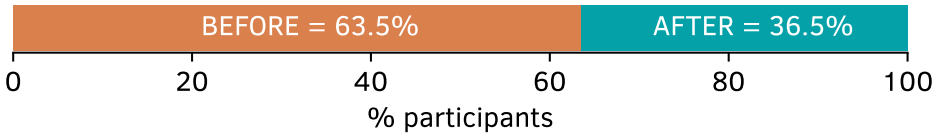

Figure 3: Prior computer exposure - *before* or *after* joining the university

prior to entering university indicated that it was easy to learn to operate a computer and that technology was easy to use. However, most of the participants without prior access to computers reported that it was not easy to learn to use a computer. This could be attributed to unfamiliarity and computer anxiety. Students, particularly African students with no prior exposure to technology are likely to exhibit computer anxiety which may impact computer self-efficacy (Chisango & Marongwe, 2021). Computer anxiety refers to being fearful of using a computer and related technologies. Students that suffer from such anxiety are likely to find it difficult to use a computer and will often avoid computer-related tasks. Therefore, computer anxiety is a crucial factor that affects students' computer self-efficacy.

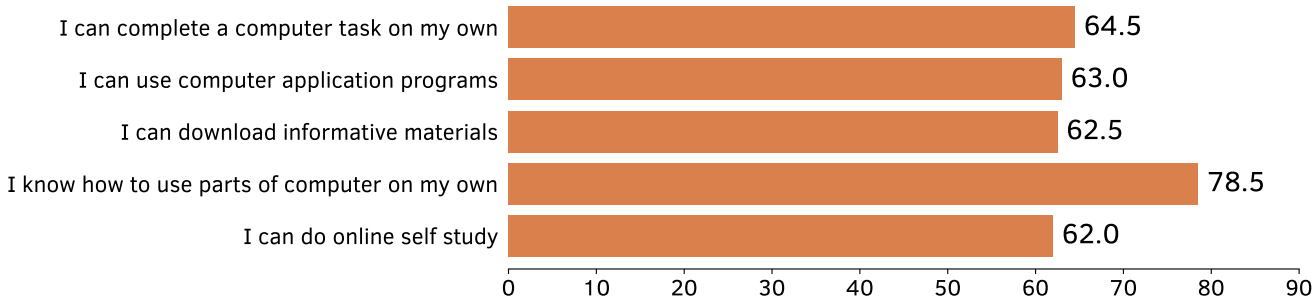

Figure 4: Student competency level with computers

It can thus be concluded that students who had access to a computer prior to entering university are likely to be more competent in their usage than those who only had access after joining the university. This is because they are more likely to have developed the skills

and confidence to use technologies. Time of access is therefore likely to impact students' computer self-efficacy. The result of a chi-squared test between the computer self-efficacy and facilitating conditions variables, shows that there is significant relationship ($p < 0.05$) between the computer self-efficacy of students and the facilitating conditions surrounding the students' use of e-learning platforms (see Table 3). Therefore, our results suggest that access to computers impacts students' competency level in the use of computers and e-learning platforms.

Table 3: Chi-squared test between CSE and FC

Value		df	Asymptotic Significance (2-sided)
Pearson chi-square	44.608	3	0.000
Likelihood ratio	47.767	3	0.000
Linear-by-linear association	37.624	1	0.000

Of the total number of participants who indicated that they did not have access to a computer before entering university (36.5%, N = 134), about 48% (N = 64) demonstrated a reasonable competency level with a computer and e-learning platforms. This suggests that even if students do not have access to any form of technology before attending university, the technological facilities provided by the institution enable them to learn how to use and access technology and its resources, which in turn enhances their self-efficacy and performance. This result suggests that higher education institutions' efforts to bridge the access and skills gap among students through providing technological resources and training is helping to alleviate the digital divide and its impact on student learning.

6 CONCLUSION

The study offers improved understanding of the factors that should be considered when integrating technology in teaching and learning. Using the CBAAM, the study found that prior exposure to computers impacts student computer self-efficacy. It was also found that unfamiliarity with technologies caused computer anxiety which negatively impacted computer self-efficacy. Lastly, the results showed that students with no prior exposure to technologies in any form acquire technological skills and perform better due to academic institutions' efforts to bridge access and skill gaps.

As in other parts of the world, the COVID-19 pandemic led to South African higher education institutions resorting to online learning platforms. Some students have struggled to adapt to this transition due to numerous factors, including the fact that they have to navigate systems on their own. When students have to stay at home, they lack peer support, which many use to share information and knowledge on campus. Therefore, higher education institutions should formulate strategies to assist digitally disadvantaged students entering university. This could take the form of technology training, and on-going technical support.

7 FUTURE RESEARCH

The study only considered first-year students. It is recommended that future research on technology integration in teaching and learning focus on all students. Given the shift to virtual technologies and online learning due to the COVID-19 pandemic, it is also recommended that future research should investigate the impact of the digital divide on such integration.

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Research Article

Covid-19 pandemic: A necessary catalyst for e-learning adoption and application

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ABSTRACT
The Covid-19 pandemic brought the world to a grinding halt, adversely affecting almost every sector including the post school education and training (PSET) sector. The South African PSET sector is no exception. The academic enterprise was abruptly disrupted and led to a serious loss of teaching and learning time as the government passed new regulations discouraging movement and physical meetings of people. The state of disaster regulations and lockdown directives pronounced during March 2020 by the South African government presented an unprecedented way of operating since the formation of many higher education institutions (HEIs). This study assesses the state of e-learning before and after the first six weeks of lockdown regulations in two HEIs, using a theoretical framework of e-learning system readiness assessment and a participatory research approach. The study reveals a state of under-preparedness by HEIs to operate under the lockdown regulations, due to the adopted blended learning policy implementation gap. Based on these findings, the study concludes with an argument that the Covid-19 pandemic presented a great opportunity for HEIs not only to adopt e-learning at the policy level but also to adapt to the new e-learning methods and practices and thus prepare universities for times of uncertainty.

Keywords: Covid-19, post school education and training, e-learning, teaching & learning, higher education institutions

Categories: • *Applied Computing* ∼ *Education, e-Learning*

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1 INTRODUCTION

The ultimate lockdown regulations pronounced at the end of the month of March 2020 by the South African government brought about an unprecedented way of operating after the formation of many HEIs in the country. This exposed the non-existence of an emergency plan to conduct teaching and learning outside the conventional norms of physical classes. The extent to which the Covid-19 pandemic had an impact, or lack thereof, on accelerating the implementation of e-learning in the PSET sector in South Africa remains innumerable.

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The Covid-19 pandemic presented a situation where physical gatherings were discouraged and wearing masks and maintaining social distancing was encouraged as the best defence mechanism to contain the transmission rate. HEIs were compelled by materialistic conditions to devise new business models to advance their educational interests. This led to a radical shift in teaching and learning and brought about the implementation of e-learning systems. Clark and Mayer (2016) defined e-learning as learning that is conducted via electronic media and resources mostly over the internet. As simplistic as it may sound, e-learning implementation was characterised as the opposite.

The South African Department of Education (DoE) (2003) accounted that its HEIs enjoyed different internet standards and viewed this as a contributing factor against e-learning systems adoption. Notwithstanding this challenge, HEIs in South Africa made serious strides towards adopting e-learning, at least at the policy level. Bagarukayo and Kalema (2015) reported that HEIs had since adopted various technology solutions to support their daily operations; not only in teaching and learning but also in support services. These included learning management systems (LMSs), online registration platforms and financial management systems among others. However, Bagarukayo and Kalema (2015) reported that LMSs were not fully utilised due to the nature and design of most universities which is contact mode driven, with only one distance learning university in the country. The unprecedented deviation from the contact mode of provision was granted by the Council on Higher Education (CHE) as a temporary measure, owing to the Covid-19 pandemic. In a communique on 20 November 2020, the CHE extended what it referred to as "the Concession for Programmes Accredited for Contact Mode of Provisioning to Continue to be offered through Remote Online Distance/Blended Modes of Provisioning" until the end of the 2021 academic year. Effectively, this implies that South African HEIs will continue to build and reap the rewards of the abrupt infrastructure development that supported teaching and learning, as well as research. This advancement could largely be attributed to the Covid-19 pandemic as it brought together all the stakeholders of the South African PSET sector and rallied them behind supporting the implementation of both new and old infrastructure technologies.

Most infrastructure technologies that have since been and continue to be implemented in the South African PSET sector are not new, i.e. they were not invented to support the academic enterprise as a direct result of the Covid-19 pandemic. The LMSs such as BlackBoard, Moodle, etc. had been adopted by a majority of South African HEIs long before the virus outbreak, but with little or no support for implementation as demonstrated in the literature review of this paper. Similarly, team collaboration applications such as Skype, Zoom, and MS Teams had been available for PSET sector use long before the Covid-19 pandemic. However, the effective power of these technologies had been ignored, neglected, undermined, or was unknown by modern society including HEIs. To test this hypothesis, this study examines the guiding regulatory frameworks of the South African PSET sector, university Information and Communication Technology (ICT) policies and practices compared to at least five ICT advanced PSET sectors and universities from around the world.

The rest of this paper is arranged as follows: Section 2 presents the motivation of the study

and Section 3 presents a critique of the existing literature. Section 4 presents the research questions. The objectives of this paper are presented in Section 5, followed by the research methodology that guided this study in Section 6. The data collection and results are presented in Section 7. The discussion and recommendations are presented in Section 8 and 9, respectively. Finally, Section 10 presents the conclusion and projected future work arising from this study.

2 MOTIVATION OF THE STUDY

This initiative is meant to contribute to the body of knowledge in the research field of e-learning with special reference to its adoption and implementation in higher education. The key element of this contribution is the evidence-based outcomes and recommendations to the PSET sector's leaders, policymakers and administrators on how e-learning systems could be better supported and managed in view of the abrupt transition witnessed.

3 LITERATURE REVIEW

This section seeks to present a critical review of how the Covid-19 pandemic has had a meaningful contribution to fostering a change of delivery mode in the PSET sector. The review uses a three-pronged approach that focuses on (i) government policy framework for integrating ICT solutions in teaching and learning against the application of the same, (ii) HEIs policy framework on digital education strategy against action plans and (iii) global best practices for the adoption and application of e-learning pedagogy. Finally, this section presents an informed analysis of how the Covid-19 pandemic has impacted teaching and learning practices in the PSET sector.

3.1 Government policy framework for integrating ICT solutions into teaching and learning

It was argued by Zanjani et al. (2017) that HEIs have for a long time been under immense pressure to implement e-learning systems to conduct teaching and learning. According to Mtebe, 2015, the greater focus of the Zanjani et al., 2017 study was on the adoption and application of LMSs, related collaborative tools and other available systems in higher education involving the digital footprint of students. Holmes and Prieto-Rodriguez (2018) stated that LMSs provided better continuity, reliability and student privacy than other platforms. Therefore, it became the primary platform used by many universities, irrespective of whether they used proprietary or open-source software. Bagarukayo and Kalema (2015) argued that while there was pressure to adopt e-learning, there was a lack of uniformity in application and this lack of a coherent approach created the possibility that the full potential of e-learning might not be realised. However, as asserted by the 2021 Technology and Innovation Report by Canton (2021)

"Recent developments in frontier technologies, including artificial intelligence, robotics and biotechnology, have shown tremendous potential for sustainable development". It remains to be seen whether the South African PSET sector, particularly the historically disadvantaged institutions (HDIs), took advantage of any development towards the adoption and application of online methodologies for teaching and learning.

A self-critique by the Department of Higher Education and Training (DHET) in its Revised Strategic Plan 2020–2025 admits that a challenge in the PSET system is the "mode of delivery and technology". Effectively, the Revised Strategic Plan 2020–2025 admits that the delivery modalities of programmes are still predominantly traditionally lecturer-centred, and that there is limited use of technology for blended learning approaches. The few colleges that use distance provision still use the traditional correspondence paper-based model, which does very little to support student success and has also been associated with poor success rates in the South African university sector. The availability of ICT infrastructure varies from college to college and is a major constraint in the utilisation of ICTs to improve teaching and learning". This self-criticism and admission by the DHET are sufficient to present the situation in the PSET system concerning ICT adoption in general and in particular e-learning. In clearer terms, ICT and e-learning adoption was never prioritised before the Covid-19 outbreak and thus the Annual Performance Plan 2021/22 committed to "expanding online learning in PSET". Regarding the expansion, the Annual Performance Plan 2021/22 states that "the Minister identified the need for online, multi-modal and blended modes of delivery to be deployed across the PSET system. This includes the building of capacity to deliver multi-modal education and training, e-learning materials development and deployment and the development of rigorous support systems to support lecturers and students". In a nutshell, only after the Covid-19 outbreak, the PSET began demonstrating some level of commitment to e-learning. However, this is not a surprise as the Commonwealth of Learning (2020) asserts that globally, "no one was prepared for the unprecedented learning crisis that needs to be addressed immediately".

3.2 HEIs policy framework on digital education strategy

The levels of unpreparedness on a global scale are informed by a range of factors such as the "lack of ubiquitous access to computers and the internet", as accounted for by the Commonwealth of Learning (2020). However, the major factor and the fundamental reason was the lack of political will by governments and education institutions to appreciate and embrace the potential and power of available technologies towards achieving national development goals. Even major economies such as the United States of America (USA) showed little appreciation of online learning before the Covid-19 outbreak, as it was only used by 15% of total undergraduate students by the end of 2019, according to Encoura, 2022. Aziz et al., 2020 reported that "since the start of online learning in 2013, it has not become a popular method not even in China. However, during the pandemic situation, it has become quite popular". According to Ngwacho, 2020, countries such as Italy, France, Germany, Australia and the United Kingdom (UK) had to "quickly enhance their e-learning platforms (Moodle, LMS, cloud systems, etc.) to

create common distance learning centre portals and provided students access to e-content and repository, due to the use of mobile devices". Similarly to the case of South Africa and many African countries, the Covid-19 outbreak proved to be a necessary catalyst for generalised e-learning adoption and application.

We argue that the Covid-19 outbreak proved to be a catalyst for the adoption and application of online learning simply because most governments boosted it with clear policies on ICT and education dating back decades before the Covid-19 outbreak. Consequently, "Nepal has formulated several ICT and education-related policies since 2000; however, the challenges it is experiencing in the advent of Covid-19 are mainly due to its faulty implementation strategies and inability to implement those policies" (Dawadi et al., 2020). The White Paper for PSET (WPPSET) approved in 2013 laid the basis for the implementation of ICT solutions in the South African education system, but there was a lack of support for its implementation. This lack of political will can also be deduced from emerging trends by various governments and education institutions targeting the expansion of online learning, increasing access to broadband connectivity and the development of strategies to provide remote support. For example, in countries such as South Africa, Kenya, Nigeria, and India, the governments have since designed a strategic plan to support remote learning (Jena, 2020; Ngwacho, 2020; Ozili & Arun, 2020). Similarly, universities also presented clear policy directions on the integration of ICT solutions in teaching and learning.

3.3 Global best practices for adoption and application of e-learning pedagogy

The Learning and Teaching with Technology (LTwT) policy of Walter Sisulu University advocated for the implementation and expansion of technology in teaching and learning. Similarly, the teaching and learning policy of the University of Fort Hare (UFH) equally advocated the promotion of blended learning by academic staff, thus highlighting the centrality of technology to enhance the student learning experience. Conversely, the University of Johannesburg (UJ) policy on teaching and learning advocated the "use of technology in the formal classroom and extending flexible learning opportunities into the wider community". Also, the University of Cape Town (UCT) "strongly encourages the use of blended pedagogy within courses and across qualifications;" notwithstanding the Senate permission for the offering of "more than 20% of total credits in fully online mode", for its undergraduate programmes. The common feature of these university policies is that they included ICT adoption for integration with teaching and learning long before the outbreak of the Covid-19 pandemic, albeit the lack of implementation detailed in their respective reviews.

In contrast to their counterparts from other first-world countries, the University of Oxford (2016) adopted its digital education strategy in 2016, which "established a framework for engagement in digital education by setting out structures, resources and approaches to enable the university to change its use of technology in teaching and learning". Since then, the University of Oxford reported that they have made progress in their online offering and

this was accelerated even more by the Covid-19 pandemic. Similarly, the University of Cambridge (2016) developed a digital strategy for education to provide a framework for developing the use of technology to support education. This strategy "is supported by an action plan, which outlines initiatives to meet each goal, primary stakeholders with responsibility or line of reporting/review, and appropriate timescales for completion".

This subsection depicts a picture of the existence of a sound policy framework for the adoption and application of e-learning in the PSET system, both locally and globally. Increasingly, even top-ranked global universities showed a lack of implementation effort in their digital education strategies. In essence, the integration of technology in teaching and learning remained at the policy level, as opposed to practice. This could be attributed to a lack of an informed and coherent action plan by various HEIs. Thus, even by their admission, the Covid-19 outbreak forced the majority of HEIs to begin to appreciate the power of available technologies currently being used. In support of this literature review, this paper presents the instant impact of Covid-19 on the adoption and application of available technologies, based on data collected from two HEIs in South Africa.

4 RESEARCH QUESTIONS

This paper sought to address some pertinent questions arising from an instantaneous e-learning adoption and implementation observed in the South African PSET sector during the Covid-19 pandemic. The main question this paper sought to address is as follows:

4.1 Main question

What was the state of e-learning implementation in the South African PSET sector before and during the coronavirus outbreak?

This question is posed to assist the investigation process to adopt and apply the necessary scientific methods to understand the influence of Covid-19 or lack thereof on the sector. Additionally, this paper sought to address the following sub-questions in an attempt to lead a focused investigation towards understanding the impact of Covid-19 on e-learning adoption and implementation.

4.2 Sub-questions

i. *What was the ICT policy direction of the PSET sector towards adopting and implementing e-learning prior to the coronavirus outbreak?*

ii. *What has been an experience-based influence of the Covid-19 pandemic in the South African PSET sector towards e-learning adoption and implementation?*

iii. *How has the state of readiness or lack thereof affected methodologies of teaching and learning during the e-learning implementation phase?*

5 OBJECTIVES

The overall aim of this study is to assess the state of e-learning usage before and during the various levels of lockdown regulations in two HEIs in the Eastern Cape province to understand the extent to which the Covid-19 pandemic has accelerated the adoption and implementation of online methodologies in teaching and learning. The following specific objectives were set:

i. *To critically review existing literature and policy positions on the original plan of action for the adoption of online methodologies in the PSET sector.*

ii. *To investigate the extent to which the implementation of e-learning has increased the university's multimodality to teaching and learning and report on the teacher and learner experiences.*

iii. *To assess the infrastructure deficit experienced by students and academics in their efforts to save the 2020 academic calendar through e-learning adoption.*

6 RESEARCH METHODOLOGY

This study applied both quantitative and qualitative methods to provide appropriate guidance about the various dimensions of the study, which include a systematic literature review and data collection and analysis procedures. Through a quantitative approach, a non-experimental design approach was adopted to understand the impact of the Covid-19 pandemic on compelling HEIs into adopting and implementing e-learning. Effectively, a purposive sampling method was used to choose two HDIs, herein referred to as University A and University B. The ICT undergraduate students and computer science undergraduate and postgraduate students including respective academic staff were targeted at University A and University B, respectively. The sample purposely focused on these two departments as the concept of e-learning could resonate very well with their purpose of existence. For this purpose, a structured questionnaire was designed to accommodate both students and lecturers. This approach proved insightful in identifying factors that influenced radical technology transformation in these two HDIs and Alshaher's conceptual e-learning system readiness assessment (ELSRA) framework was used as a baseline in the university's state of readiness analysis (Alshaher, 2013). Additionally, this study followed a qualitative research approach and thus centred the study within phenomenological research, to gain insights into the experiences of both students and academics concerning the phenomenon of the Covid-19 pandemic and teaching and learning pedagogies in the two HDIs. The main reason for adopting this mixed-method approach was to lay grounds for generalising the findings of this study and further articulate the meaning of the phenomenon of the Covid-19 pandemic as a catalyst for e-learning adoption and application, as conceptualised by Creswell and Creswell (2018).

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7 RESULTS

A survey questionnaire was designed and circulated among tertiary students of two historical disadvantaged institutions located in the Eastern Cape, South Africa. This was purposive sampling, targeting students from first year to the postgraduate level of two departments (Computer Science and ICT).

7.1 Age group and level of study

An analysis of the age and level of study of participants is pivotal to also give a proper account of who the participants are and what level of study they are in, which is significant to show whether the various ages and various levels of study have different perspectives and experiences with e-learning applications. Figures 1 and 2 demonstrate where the large participation comes from in terms of age and study level. Major participation is from ages 22–27 while in the study it is from levels 2 and 3. These are students who would have had a year or more within the university setup who have participated in various studying platforms. This is followed by the age group 17–21 which comprises mostly first time entries at the university, who have just been introduced to the university environment.

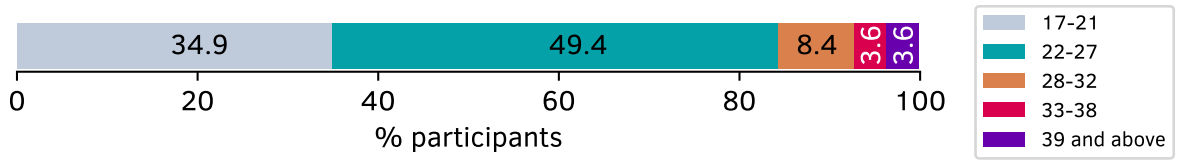

Figure 1: Age of participants in years.

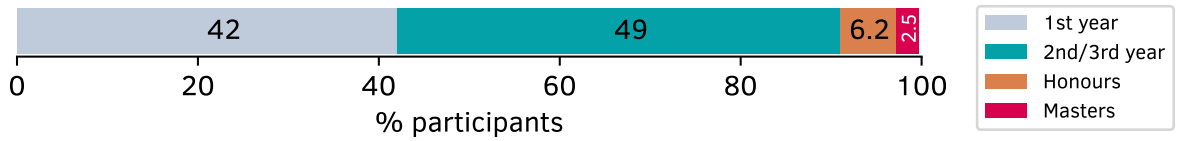

Figure 2: Level of study.

7.2 e-Learning concept understanding and use before Covid-19

Similarly, students in the majority confirm to possess a basic understanding of e-learning. Almost 60% of participants said they know e-learning. Almost 30% of participants were not sure if they knew enough to answer the question about e-learning. This group is largely from first year level of study. We argue that this is also informed by the change in the environment. Lastly, just over 10% confirmed that they did not know the concept. Figure 3 must be looked at

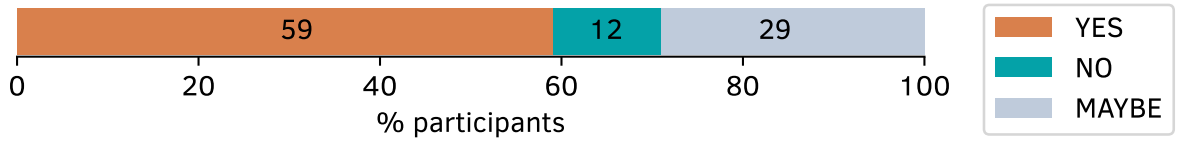

Figure 3: Understanding of the e-learning concept.

as well as the concept reflected in Figures 1 and 2 Based on this response presented in Figure 3, it is safe to conclude that most of our participants understand the concept of e-learning.

Figures 4 and 5 summarise whether according to our participants they had ever used e-learning services before the Covid-19 era in their learning environments. Figure 4 has the highest response with 77% of participants saying NO and just 19% saying YES. This links with Figures 5 where each participant was asked whether they had performed any tasks on the platforms. Over 51% of the participants said they had never performed any task, while 32% confirmed they had only accessed notes and learning materials.

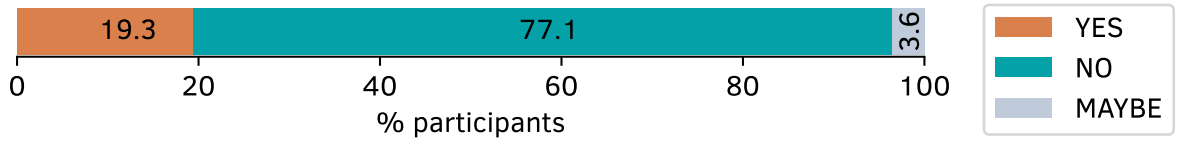

Figure 4: e-Learning use before Covid-19.

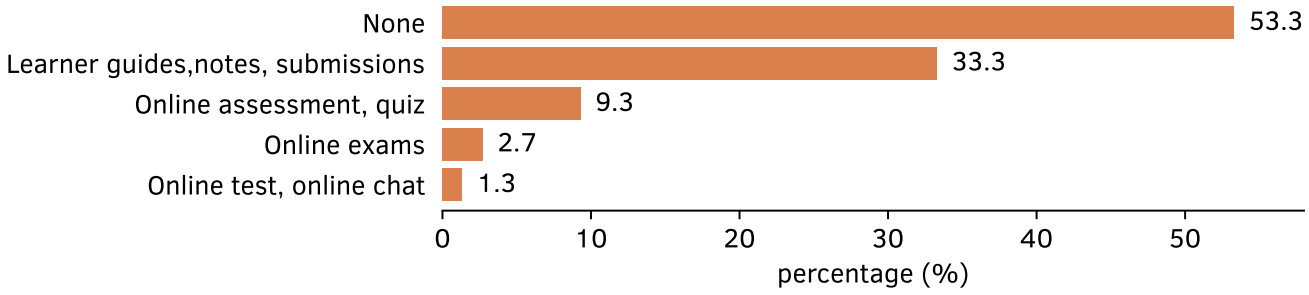

Figure 5: Use of e-learning service before the emergence of Covid-19.

7.3 e-Learning application during Covid-19

Figures 6, 7 and 8 present a summary of activities, tasks and usage of e-learning services during Covid-19. Figure 6 shows us a drastic increase in the use of e-learning (compared to Figure 4) while Figure 7 summarises which main tasks are being done and Figure 8 shows which platforms are used in the majority by participants. In summary, the figures show how during the

Covid-19 era changes happened. Figure 4 showed us that there was minimal implementation of e-learning before Covid-19 appeared.

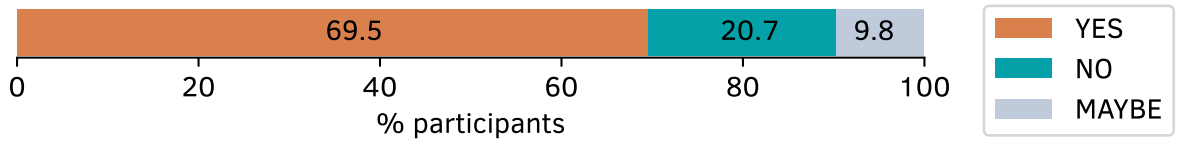

Figure 6: e-Learning use during Covid-19.

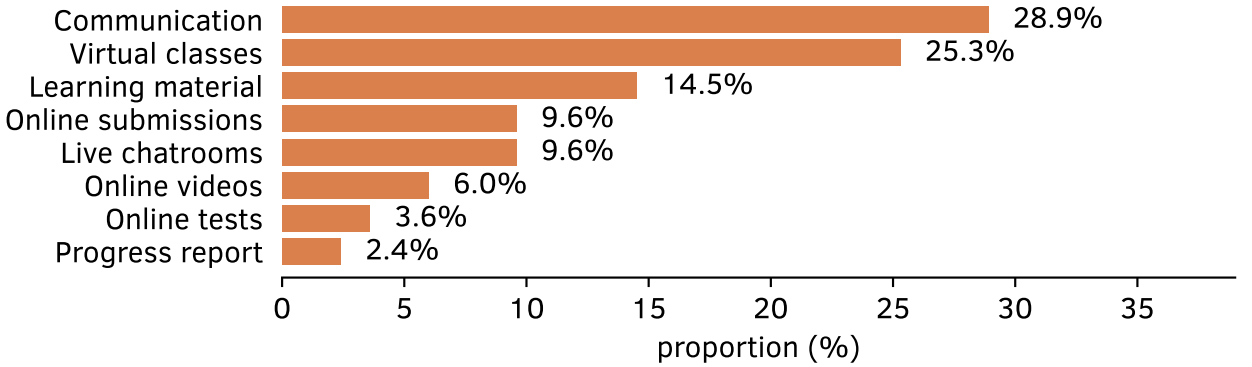

Figure 7: Activities done on e-learning during Covid-19.

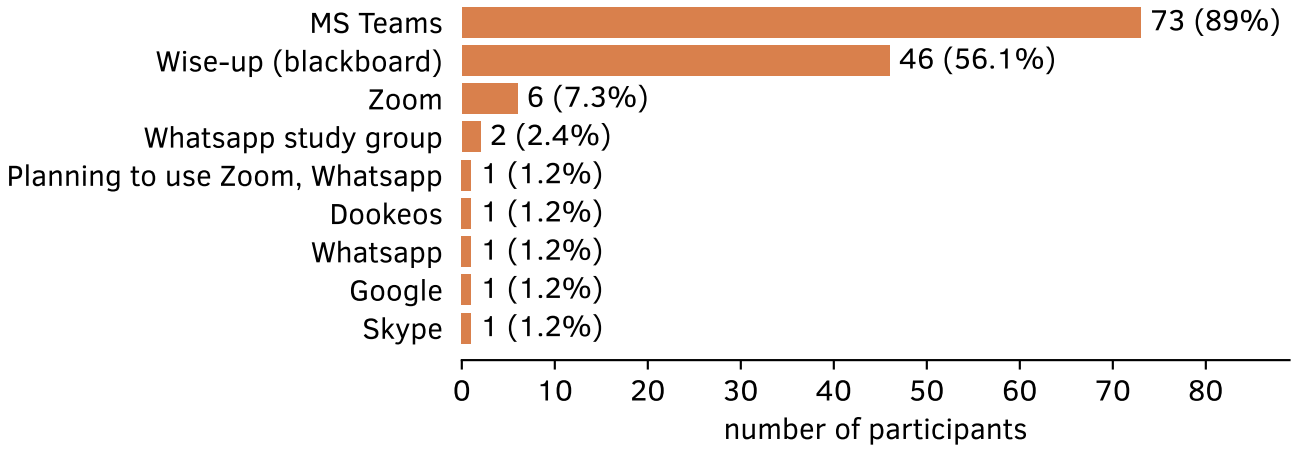

Figure 8: Platforms used by students.

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7.4 University technical support for students to have access

This section presents data about the level of technical support if any, provided by universities to students to access and use e-learning systems during the pandemic.

Figures 9, 10 and 11 demonstrate that some strides were made by universities to provide devices for access to e-learning services, thus providing data for remote access and technical support to provide short training and support to students during submissions and access to learning material. All three graphs show the support while some still offered aid in the form of resources concerning data and the use of devices. Figure 9 shows that universities provided laptops for the first time during Covid-19 to their students, while Figure 10 showed 80% of participants saying that their means of connection depended on the university's provision of data.

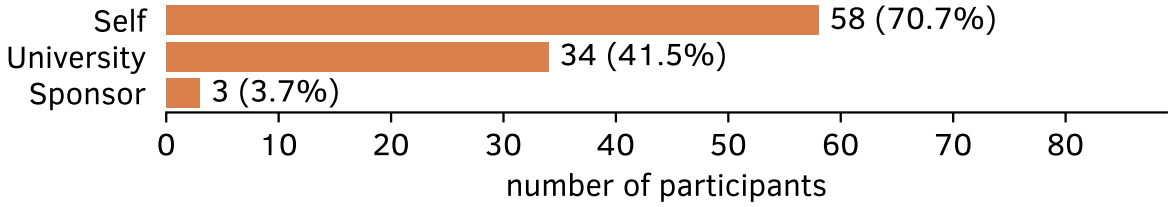

Figure 9: Provider of accessed devices.

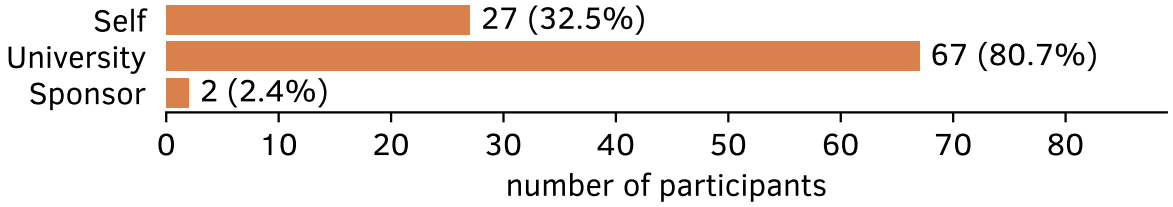

Figure 10: Provider of data to connect remotely.

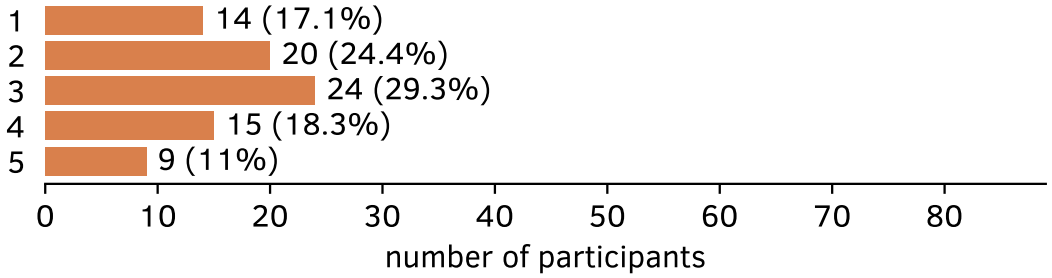

Figure 11: Rating of technical support provided by the university.

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8 DISCUSSION

Towards achieving the overall aim of this study, which is to determine whether the Covid-19 pandemic has accelerated the adoption and implementation of e-learning or not, the following themes are drawn from the collected data to discuss the findings.

Theme 1: Knowledge and experience of e-learning

In line with our purposive sampling approach, this theme sought to verify, as an entry point to the discussion, if the participants were knowledgeable and experienced about the central research aspect of e-learning. Alshaher (2013) reported that measuring students' knowledge and information technology skills before introducing a new system is a critical factor in assessing the state of readiness. The responses to the questions: "would you say you understand what is e-learning", "e-learning use before Covid-19", and "use of e-learning services pre-Covid-19" provide the basis for our discussion for this theme. For each of the three categories, varying responses were collected. In the category of "would, you say you understand what is e-learning", about 59% of the respondents claimed to know what e-learning is, 12% claimed to not know and 29% were not sure. This suggests that 59% of the participants were knowledgeable about e-learning and thus were fit for the purpose. In the category of responses "e-learning use before Covid-19", about 77% of respondents said they had never used e-learning platforms before the Covid-19 outbreak. 19% had used e-learning and only 4% were not sure. The mode from this category is 77%, suggesting that most of the respondents never used e-learning. What can be deduced from these two categories is that even when respondents had never used e-learning they knew what e-learning was. Probably, therefore they were able to respond to the category regarding "use of e-learning services pre-Covid-19".

In this category, the mode reflected that 51% of the respondents had never used e-learning services before Covid-19. Notwithstanding the positive attitude towards ICT policy directions at the time, the experience of the respondents showed a lack of policy implementation. Furthermore, these results showed that 77% had never used e-learning before, which showed that the skills dimension of Alshaher's framework showed that universities were simply not ready to introduce e-learning systems. By extension, this could mean that even academic staff were not ready to manage the e-learning programmes to support students, as the respondents included both staff and students. Therefore, it can be deduced that there was no "sufficient manpower" as Alshaher (2013) refers to it in the ELSRA staff dimension, to ensure the proper adoption of the e-learning system.

Theme 2: e-Learning application during Covid-19

The responses show that the use of e-learning during Covid-19 registered a sharp increase to 70% which is consistent with the global trends on how Covid-19 changed the status quo. This is also evident from the responses on "Activities done by users on e-learning during Covid-19",

which showed that communication and virtual classes were increasingly being done online. These activities were conducted mainly on Blackboard and Microsoft Teams, as depicted in the platforms used by students' responses (Figure 8). In essence, e-learning began to characterise the mode of operation in these two universities, as a result of the Covid-19 outbreak. This answers the question of whether the Covid-19 pandemic had any influence on the adoption and implementation of e-learning in the South African PSET sector.

Thus, the experience of the respondents demonstrates that e-learning usage drastically increased during the period of the Covid-19 pandemic. Based on the results presented in Theme 1, the exponential increase in e-learning system usage was by accident, not by design. This is contrary to Alshaher's contention on the e-learning strategy that it must be a "systematic and comprehensive plan of action designed to ensure the success of a broad-based e-learning initiative that adds value to organisations in ways that are supportable and sustainable" (Alshaher, 2013). The exponential increase in e-learning system usage without "sufficient manpower", as argued in Theme 1, meant that universities could not guarantee the provision of the necessary support and sustainability of the project, as discussed in Theme 3.

Theme 3: Infrastructure deficit experience

It was evident from the literature review that HEIs did little to create an enabling environment for e-learning implementation. The data in the "Device to have access provided by?" category showed that students were self-reliant at the beginning of e-learning implementation in terms of devices. However, the data in the "provider of data to connect remotely" category showed that HEIs played a big role in providing data for connectivity to e-learning platforms. Probably, loading student data was an easier intervention for HEIs, compared to other interventions such as purchasing equipment and providing training education and technical support. Alshaher (2013) argued that training and education are critical factors for e-learning users such as the project team, staff and students, as this factor familiarises stakeholders with the concept of the e-learning system. Finally, the data also showed an unstable but above-average performance of HEIs in the "Technical support provided by university" category.

This demonstrated two things: first, the efforts of the universities to provide great service in a time of need; and second, their inexperience in playing this role. Teaching and learning were affected by the HEIs' poor state of readiness to implement e-learning solutions, as the data showed that at the beginning of e-learning implementation, students had to rely on their own resources. In a third-world country like South Africa, with a leading global inequality ranking, some students might have been adversely affected by a lack of access to resources and a poor state of readiness. Where there was a chance for students to use their resources to participate in the e-learning programmes, universities were certainly not ready for this project at that time. Alshaher (2013) proposed that technology is "one of the important requirements of the success of an e-learning system" and that access to technological resources had to be made easy and fast, to allow stakeholders to consume hosted e-learning material and ensure that teaching and learning enterprises were not compromised. This is contrary to what was

depicted by the data presented in this theme and Theme 4 further alludes to this experience.

Theme 4: Impacts of abrupt implementation of e-learning

As a pedagogy, online learning has some prerequisites for efficiency and effectiveness which include time, tools, resources, knowledge and skills (University of Witwatersrand, 2021). Data on the "during Covid-19 e-learning use" and "Activities are done by users on e-learning during Covid-19" categories showed that the Covid-19 outbreak pushed HEIs towards emergency capacity building based on available technologies; as reflected in the "platforms used by students" and "provider of data to connect remotely", categories, among others. The data presented in Figure 7 showed that only 14.5% of activities done online could be attributed to "learning material", which implies that e-learning systems presented limited content for consumption, as opposed to virtual classes and live chatrooms.

It can be deduced that this manifestation confirms Alshaher's (2013) argument that "for some organisations, it might be difficult or undesirable to transfer certain training content to the internet or an intranet". Consequently, Alshaher demonstrates that "work processes that require certain physical skills may not be practical or feasible to teach using a computer". In essence, no under-prepared university could have successfully transferred training content online overnight, and limited activities relating to learning material could suggest that indeed universities were not ready. Additionally, the Covid-19 outbreak was extremely effective in demonstrating to HEIs and governments that their long-standing commitment to integrating technology in teaching and learning can now be realised fully. It demonstrated that such required technology is now available and experiential learning (learning by doing) is the best teacher in terms of building knowledge and skills. However, a better-prepared university could have chosen the appropriate technology including the e-learning platform before the e-learning course design alone, as Alshaher's ELSRA provides guidance on. However, the opposite paints a clear picture of what was the state of e-learning implementation in the South African PSET sector before and during the coronavirus outbreak.

9 RECOMMENDATIONS

Due to the position reflected in the literature review, Alshaher's (2013) ELSRA and the data analysis of this study, the following is recommended:

i. The implementation of government and HEI policies on digital education, given the radical shift caused by the Covid-19 outbreak in the PSET system, should take place with immediate effect.

ii. HEIs should now devise clear digital education policies, such as those provided by UCT, to comprehensively articulate the framework and modalities of e-learning implementation.

iii. Continued efforts should be made to build and reap the rewards of the limited infrastructure development that support teaching and learning towards the realisation of blended learning.

10 CONCLUSION

This study embarked on a data-driven research journey and reviewed literature that discussed how effective the Covid-19 outbreak was in accelerating the adoption and application of e-learning in the PSTE sector. The literature review clearly showed that before the Covid-19 outbreak the policy framework facilitated the adoption of e-learning in the PSET sector, notwithstanding the lack of implementation to date. The data analysis supported the literature review findings that showed that students and academics overwhelmingly stated that they had never used e-learning before. Thus this study concludes that Covid-19 was a necessary catalyst for e-learning adoption and implementation because both governments and HEIs had committed to technology integration with teaching and learning even before Covid; however, implementation was severely lacking. Based on the findings of this study, it would be of great interest to understand the extent of implementation of e-learning under the prevailing post-Covid conditions.

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Research Article

Grade 9 teachers' experience of digital technologies in the classroom

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ABSTRACT
The use of digital technologies in the classroom has escalated, especially during the COVID-19 pandemic. Although technology and teacher development centres are available for teachers to use, they are often not optimally utilised. This study used explorative qualitative case study methodologies to understand Grade 9 teachers' use of digital technologies as they integrate it into their lessons and classrooms. Seven teachers were purposely selected to be sources of data collection. Framed by the Technological Pedagogical and Content Knowledge (TPACK) framework, data was generated using semi-structured interviews to explore the Grade 9 teachers' experiences and views on the integration of digital technology post the outbreak of the COVID-19 pandemic. To analyse the data, a thematic analysis was conducted. Although the findings show limited digital technology integration, some teachers are found to be using videos, projectors, and laptop computers in their classrooms. Inadequate infrastructure and lack of support contribute and impact teachers' experience of integrating digital technology in the Grade 9 classroom.

Keywords: COVID-19 pandemic, digital technology integration, rural schools, teacher experience, technology knowledge

Categories: • *Applied Computing* ~ *Education, e-Learning*

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1 INTRODUCTION

The 21st century is characterised by irresistible emerging technologies and more significantly, has seen dramatic changes in the education system across the globe (United Nations, 2021). These changes in education are mirrored in the amount of digital technology that has infiltrated education, hence, as a branch of knowledge construction, education needs to be redesigned to make provision for the challenges brought by these emerging digital technologies (Ganimian et al., 2020).

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While the use of digital technologies has resulted in large scale transformation in education across the globe, teachers as leaders in the teaching and learning environment (Collie et al., 2018), emerged as one of the main role players and role models to deliver education both in- and outside of the classroom (Hicks, 2011). With so much exposure to the 4IR digital technology, teachers hardly have a choice other than to embrace the new technology and facilitate interactive teaching and learning to 21st century learners (Abukhattala, 2016). When teachers experience a sense of achievement and satisfaction while using digital technologies, they become more attracted to the continuous use of digital technology (Chigona, 2018). The use of digital technologies not only influences teachers' pedagogical approaches, but also has a positive impact on the achievement of learning outcomes (Chandra & Mills, 2014).

As the use of digital technologies in the 21st century is expanding, opportunities are created to deliver an interactive learner-centred approach to education (Fransson et al., 2018), utilising the affordances of digital technology. The current education system promotes the use of digital technologies where teachers are enabled to support learners from diverse backgrounds (Van Greunen et al., 2021). Therefore, all teachers need to be familiar with these digital technologies to integrate them into their classroom activities or lessons, moreover, keep up to date with new developments in digital technologies.

Researchers have reported many benefits based on the use of digital technology over the past years (Abukhattala, 2016; Azmi, 2017; Nikolopoulou, 2020). For example, when English language teachers integrate digital technology into their lessons, learners are motivated, engaged and enjoy the classes; hence the learning is enhanced and it boosts autonomous learning (Abukhattala, 2016; Azmi, 2017). Similar results were reported in a prior study (Nikolopoulou, 2020) which added that learners also have easy access to information when using digital technology.

Further studies report that insufficient facilities either discouraged teachers to use digital technology or forced them to buy their own resources (Abukhattala, 2016; Nikolopoulou, 2020). Since all teachers are not computer literate, it makes the adaption to the utilisation of digital technology to prepare lessons time-consuming (Abukhattala, 2016; Hill & Uribe-Florez, 2020; Hyndman, 2018), where another study found that experience, age, and gender were not deciding factors as to whether teachers will use digital technology or not (Abukhattala, 2016). Thus, for this study the purpose was to explore how teachers experience the integration of digital technologies in Grade 9 classes, while being challenged to continue with teaching and learning during the COVID-19 pandemic.

2 BACKGROUND

Although investment in digital technology has increased dramatically over the past two decades (Lim et al., 2013), concerns exist regarding benefits and the return on investment. According to Lim et al. (2013), a gap exists between schools having digital technologies and the actual use of the technologies. In South Africa, the scenario is not much different from what was observed in Lim et al.'s (2013) study. Since the South African Department of Basic

Education has embarked on various projects to dispatch digital technology, such as interactive whiteboards (Ngcume, 2021), laptops (Macupe, 2017), and tablets to schools in the various provinces (Govender, 2021), a common trend emerged that irrespective of training been given, albeit limited, technology is not optimally utilised (Mihai, 2020).

The onset of the COVID-19 pandemic caught many schools off guard as schools needed to close and adapt to remote teaching (Winter et al., 2021). Several challenges such as security of devices, teacher student ratio, electricity (load shedding), the lack of training on how to use digital technology effectively as teaching and learning tools, amplified the reality of not being able to implement remote learning (Schleicher, 2020). All countries managed to implement some form of remote learning in their educational programmes during the COVID-19 pandemic (The World Bank, 2021). Technologies such as TV, radio, and online and mobile platforms were deployed with mixed success. For example, some learners in low-income countries or poor socio-economic home surroundings could not participate in these remote learning strategies, resulting in more than 50% of the learners in these areas missing out on learning activities. While the pandemic magnified the digital inequalities (Du Preez & Le Grange, 2020; The World Bank, 2021), there were attempts to lessen the digital divide and suggestions made that focus should be placed on three areas, namely infrastructure, human resources, and logistical and administrative systems. This article focuses on the second area, with particular focus on teachers' experience of integrating digital technologies to deliver lessons.

During COVID-19 teachers continued to struggle to adapt to the digital technology integration (Akram et al., 2021). To assist teachers in using digital technology in a pedagogically sound way, the focus in this study is on how teachers' experience digital technologies to deliver lessons. The secondary schools used in this study are situated in rural areas within the Bojanala District, North West province, in the Dinaledi cluster. Due to limited digital technological equipment at the selected secondary schools, a computer laboratory was built at the Teachers Development Centre, located in one of the villages in the district, for teachers and learners to make use of. For the schools to have access to quality education and ICT infrastructure, the computer laboratory manager trains teachers on issues related to digital technologies used in teaching and learning, when the need arises. Although the computer laboratory can be used, the geographical location of schools hinders teachers from implementing what they have learned during the training in the computer laboratory because of the lack of digital devices and Wi-Fi at their schools.

This study forms part of a greater research project where the application of the TPACK framework and each component will be applied. Through the three years of the research project, the TPACK framework and the intersections of each one will be applied to assist teachers to integrate technology effectively in their classrooms. The exploration of technological knowledge (TK) would initiate the intervention process that will be done to assist Grade 9 teachers to be knowledgeable about TPACK constructs and how to apply them in their teaching and learning.

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3 PROBLEM STATEMENT

Irrespective of the popularity of digital technology, the positive role that teachers play in integrating technology and the possible advantages of the use of digital technology in the classrooms, many teachers and schools in South Africa, for various reasons, still resist the use of technology or have low levels of digital technology integration (Van Greunen et al., 2021). Despite the advantages that digital technologies, such as laptops, tablets, and Wi-Fi provide and the urgency for online education highlighted by the world-wide pandemic, digital technology integration is still low (Mihai, 2020), specifically regarding many teachers and schools in South Africa.

In the Dinaledi cluster, Bojanala District in North West Province of South Africa, training opportunities and access to the Teacher Development Centre computer laboratory provides teachers with opportunities to develop the necessary knowledge and skills on how to use digital technologies to support learning and deliver lessons. However, the computer laboratory manager indicated that teachers are reluctant to attend training and only a few utilise the computer laboratory which raises concerns as teachers in the 21st century are expected to play a key role in optimally enacting the use of digital technologies to facilitate teaching and learning (Fransson et al., 2018). This leads to the question 'How do Grade 9 teachers experience integrating digital technology in their classroom', especially when teachers do not make use of the training opportunities provided. This prompted the researchers to take a further step and determine how teachers use technology and what challenges they experience. The TPACK framework, more specifically the TK construct, is used to explain the knowledge that teachers need to integrate digital technology in their classrooms (Mishra & Koehler, 2006).

4 THEORETICAL FRAMEWORK

As mentioned earlier, TPACK (Koehler et al., 2009) was identified as a suitable framework for the present research project. TPACK describes the role of technology, pedagogy, and content knowledge and how the intersection of the constructs influences technology integration in teaching and learning (Figure 1). TPACK further describes a framework where the nature of technology coupled with the complexity of integrating technology in the pedagogy of teaching and learning is considered. This bond between technology, content, and pedagogy provides knowledge needed to successfully integrate technology in digital learning.

A previous study (Akram et al., 2021) assessed online teaching skills of teachers during COVID-19 and found that TK was the lowest. Hence, the present study focuses only on TK, specifically how Grade 9 teachers experience the integration of digital technology in the classroom.

Defining TK is said to be notoriously difficult as it becomes outdated by the time the study is published (Koehler et al., 2009). This is due to the ever-changing nature of technological tools and resources. Although TK, as understood within the TPACK model, is seen as the fluency of information technology which moves beyond traditional computer literacy, it is rather

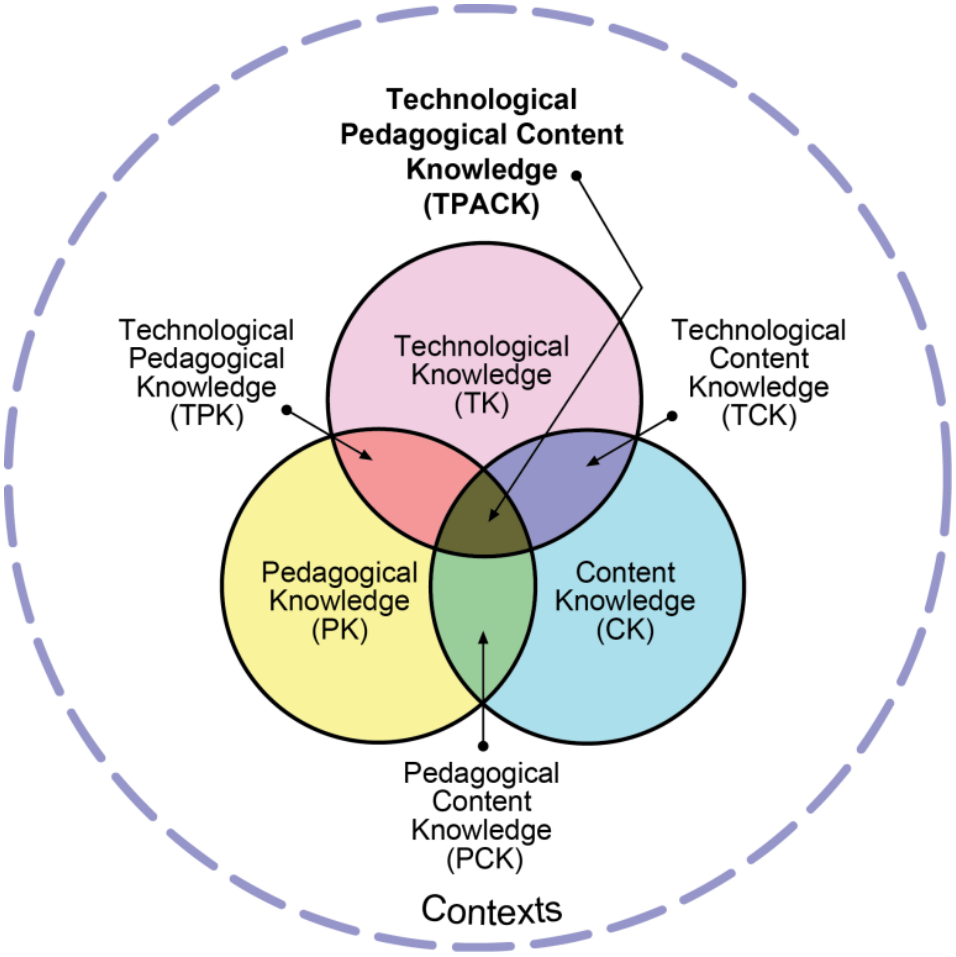

Figure 1: The TPACK framework and its knowledge components [a]

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the ability to implement information technologies for teaching and learning purposes (Koehler et al., 2009). There is a deeper level of understanding that involves the mastery of information technology to process, communicate, and problem solve. While TK is a developmental construct that is constantly evolving, it could be achieved through open-ended interaction and repetitive use of technology (Koehler et al., 2009) and refer to the knowledge teachers have of emerging digital technology (Cox & Graham, 2009). The integration of technology is a complex matter because of its volatile nature (Koehler et al., 2009) as well as the uniqueness of the challenges that come with the use of each digital technology. For example, when teachers need to create documents on a laptop, they can do so with or without having electricity, however, if they need to share documents with learners (connectivity), electricity is needed for an Internet connection. Therefore, having unreliable electricity at schools influences the utilisation of digital technology.

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Therefore, a focus on the TK includes how the technology works and that the integration of the digital technology itself is key (Koehler et al., 2009). Appropriate digital technology needs to be selected to suit the content intended to be delivered. When integrating digital technology in the classroom, it becomes the change agent even though it was not designed specifically for education (Dietrich, 2018) as it could transform content and lesson delivery. Therefore, in this study TK was used to guide the research in framing the interview questions. The questions were built around aspects such as the access teachers have to digital technology, how they integrate and experience using the digital technology, and what kind of challenges they experience or support they get or need.

In this study teachers had to practise their teaching under challenging circumstances. Not only were they amidst a pandemic which caused schools to implement various kinds of social distancing, sanitising, and rotational attendance measures, they were forced to use digital technology in an environment that lacked electricity, security, and sufficient Internet access / data. It is within this scenario that the present community project was launched to use the TK part of the TPACK framework to determine how Grade 9 teachers use digital technologies to support learning and deliver lessons in their teaching and learning environments.

5 METHODOLOGY

An explorative qualitative case study (Creswell, 2014; Maher et al., 2018; Yin, 2018) was conducted in the Bojanala District, North West province, the Dinaledi cluster. This district was chosen since the schools do have some digital technologies that were sponsored or provided by the South African Department of Education. The researchers aimed to explore how these digital technologies were being used for lesson delivery.

5.1 Sample

A purposeful sample of seven Grade 9 teachers were interviewed online due to COVID-19 regulations at the time. In qualitative research, purposeful sampling is often used to select participants who have an interest in the matter under investigation (Palinkas et al., 2015). The teachers were selected based on the grade they taught. In some schools it is a practice for Grade 9 teachers to follow their learners to the next grade and scaffold their learning as they progress from one grade to the next. For example, the same mathematics teacher in Grade 9, will in all likelihood be the learners' mathematics teacher in Grade 10 since they know what scaffolding they have done to guide learners as they learn new concepts and construct new knowledge. While this study is part of a three-year project, the data collection focuses on Grade 9 teachers. In three years, class visits, document analysis and implementing an intervention for the same group of teachers is being done, while they teach Grades 9, 10 and 11.

5.2 Data collection

To collect qualitative data for this explorative case study, semi-structured interviews were designed and conducted virtually or telephonically after school hours using Microsoft Teams or a voice recorder (Smith, 1995). Semi-structured interviews allow the researchers to clarify concepts, probe for more detail, and to ask participants to explain their responses (Bless et al., 2013). The interview questions were designed based on the TK construct of TPACK and keeping the research question in mind. Permission was obtained to record the interviews which were conducted over a 30-minute time period. The interview consisted of open-ended questions which relate to what digital technology the teachers have access to, how they integrate technology in the classroom and what challenges they experienced. The collection of data included teachers' authentic experiences of using various digital technologies to plan and deliver lessons. These interviews were transcribed and analysed to identify themes related to teachers' use of digital technologies in their Grade 9 classrooms.

5.3 Data Analysis

After the interviews were transcribed, a thematic analysis was carried out where the text was identified, analysed, and interpreted (Braun & Clarke, 2006). First, the text of the transcript was read with the research questions in mind (deductively), with emphasis (highlight) placed on what digital technology the participants used (TK), how they experienced the use of digital technology, what challenges they experienced, what support they received, and their suggestions for improvement. From this thematic analysis, the responses were grouped according to themes which guided the presentation of the findings.

5.4 Ethical clearance

The principal investigator requested permission to do the project at nine schools in the Dinaledi cluster within the Bojanala District, Northwest province, through the University of South Africa's Ethics Committee. Furthermore, an entry request to the nine schools in the Dinaledi cluster was sent to the acting sub-district manager at the time. Letters to the respective principals of the schools asking permission to interact with teachers were also considered. Ethical consideration was maintained by using voluntary participation, informed consent, anonymity, and confidentiality. To ensure anonymity, the participants' names were not disclosed, however, their responses were labelled as T1 to T7 respectively.

6 FINDINGS AND RESULTS

This study explored Grade 9 teachers' use of digital technologies in their classrooms. The research question 'How do Grade 9 teachers experience integrating digital technology in their classroom' was formulated and used to reveal opinions and experiences of Grade 9 teachers in integrating digital technologies in their lesson delivery.

There was no apparent reason for gender, age, and experience preference in this study, however, it does provide the context and background of the participants. As Table 1 illustrates, five of the participants were the so-called digital natives (born after 1980), while the other two participants are digital immigrants (born before 1980) (Prensky, 2001). All the participants teach Grade 9, however, some of the participants also teach subjects that range from Grades 8 to 12 (Table 1). The influence of gender, age, and experience was not investigated, since a previous study (Abukhattala, 2016) found that these factors do not influence digital technology integration in secondary schools.

Table 1: Biographical data of participants

Participants	Gender	Age	Grades teaching
T1	F	31–40	8 9 11 12
T2	M	20–30	9 11 12
T3	F	20–30	8 9 10 11 12
T4	M	20–30	9 10 11 12
T5	M	20–30	8 9 10
T6	M	51–60	8 9 10
T7	M	41–50	8 9 10 11 12

Prior to exploring how teachers experience the integration of digital technology in their classrooms, it was important to have an indication whether teachers have access to digital technology and what digital technology is available and used. For example, in Figure 2, it is evident that all seven participants indicated that their schools have laptops and projectors, while the applications used are minimal (only one or two of the participants are using the devices available to them).

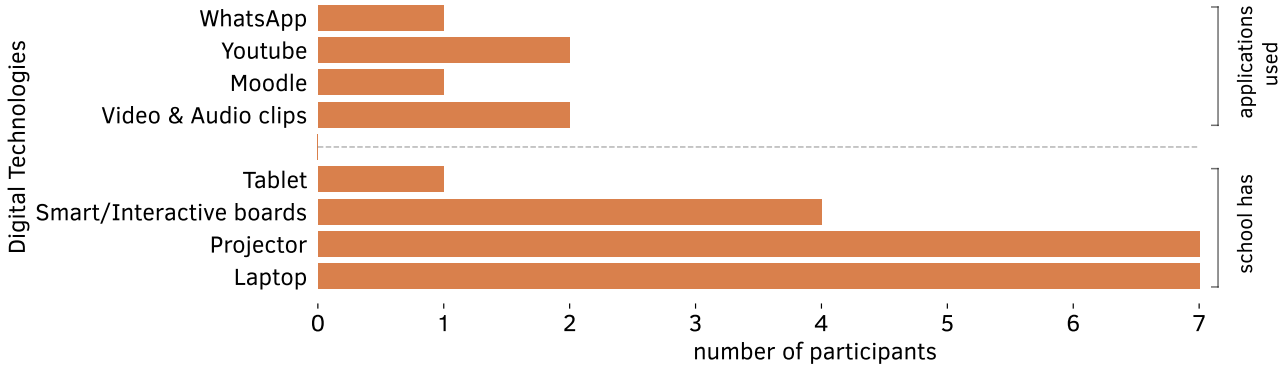

Figure 2: Digital Technology available at school [T1–T7]

Apart from the biographical data (Table 1) and the digital technology that the teachers used (Figure 2), three themes emerged: limited integration of digital technologies; lack of

infrastructure; and support in the use of digital technologies and experience in using digital technologies. The presentation and discussion of the findings are concurrently done. Seven participants shed light on their experiences regarding delivery of lessons using digital technologies and the support rendered to learners in teaching and learning.

6.1 Limited integration of digital technologies

The integration of digital technologies in the context of this study is a concern. Only two [T2; T4] of the participants deliver lessons regularly using digital technologies. Their reaction is that,

> *"The integration of digital technologies is not taken seriously in Grade 9 because priority is given to the Grade 12,"* [T5]

referring specifically to the subject content. It appears the priority of the school is to use technology for the Grade 12 subjects (higher grades) rather than the lower grades. Since Grade 12 is the entry requirement to higher education, their syllabus gets preference. This raises a concern, since teachers should understand how to use different digital technologies to transform the delivery of lessons irrespective of the grade they teach and should not limit the use of technology only to higher grades. According to a previous study (Koehler et al., 2009), TK requires a deep understanding of a variety of digital technologies to process, communicate, and problem solve when teaching the content.

Contrary to the findings of this study, an earlier study (Beardsley et al., 2021) revealed that the integration of digital technologies has increased and the teachers are motivated to improve their digital skills as they proceed using digital technologies for delivering their lessons. In the current study emphasis is on delivery of lessons using digital technologies. Participants used:

> *"a laptop as well as the data projector, sometimes the interactive white board to show them my activities."* [T4]

In other instances, YouTube videos are downloaded while connected to Wi-Fi at the participants' respective homes [T2] and this allows the learners to watch and listen to the video clip at school without Internet connection (offline) or video lessons are downloaded and sent to learners after hours [T3]. Audio clips were also sometimes played, for example:

> *"I make use of audio for listening comprehension activity, they can listen to and then they also write or ask questions that I have given them."* [T1]

Learners are requested to respond to questions after watching the videos or listening to the audio clips. Two participants [T6; T7] did not integrate digital technologies into their lessons. Participant [T7] admitted:

> *"Not really, I don't use any digital, it is just like I don't know whether to call it an older traditional teaching and then at times if I have like certain lessons, maybe where there are teaching aids, nothing really digital."* [T7]

Although the integration of digital technology was limited, the participants' views on the use of digital technologies agrees with an earlier study (Huang et al., 2021) that there is always a positive impact in teaching and learning. A further study (Dzakpasu & Adom, 2017) found that digital technologies have impacted favourably on the digital technology integration of teachers. Teachers' perceived knowledge of how to effectively integrate digital technologies in teaching and learning is lacking, which makes delivery of content inadequate (Chigona, 2018). However teachers have no choice but to embark on the use of digital technologies to deliver their lessons, since digital technologies play a significant role in paving learners' future careers paths and enabling them to become informed citizens. Since the present study found that technology is not often used, the TK is lacking, making it nearly impossible to implement lessons using technology (Cox & Graham, 2009).

6.2 Inadequate infrastructure and support in the use of digital technologies

Since the common digital technologies identified by the participants at their schools were laptops and projectors (in Figure 2), the challenge is to use them since many have no Internet and sometimes no electricity. In some schools only a few of the classrooms have electricity and in some cases the laptops are locked away and it takes time to sign them out and take them to the class [T3]. Four of the schools have either a smart board or an interactive whiteboard while the Grade 12s have tablets to use [T5]. The following excerpt bears evidence:

> *"Our school has the interactive white boards, it also has the projector, and then laptops, yes, and that is what we have in our school."* [T4]

Another participant [T5] said;

> *"All teachers have laptops, there are 2 projectors in our school and a smartboard. Grade 12's (students) have been given tablets."* [T5]

The available digital technologies in a school plays an essential role in the integration of digital technologies. Although not all schools have the same digital technology available, digital technology integration is possible, however, dependent on the type of digital technologies a school has. In a previous study (Kundu et al., 2020), the empirical findings revealed that the integration of digital technologies was delayed as a result of moderately low infrastructure and poor teachers' perception on digital technologies integration. Bariu (2020) echoed a different sentiment, where the availability of ICT infrastructure necessitates the need for transforming the delivery of content. Teachers can only be encouraged to integrate digital technologies in their lessons if a variety of devices are available for use within a school. Furthermore, the

provision of infrastructure should be the appropriate choice of digital technologies that should be used to advance student learning and understanding (Koehler et al., 2009).

The lack of training on how to integrate technology can increase the dependency on support and can be another reason for teachers not to use digital technologies in delivering their lessons. Only one participant mentioned receiving formal training while at university, however, the remainder did not receive any background training. However, the eagerness of some teachers who are integrating digital technology is evident:

> *"I have no formal training as I did not do computer science, I just started using the computer."* [T2]

Similarly, one participant also commented that:

> *"Eish I did not receive any training, I just learned how to use these by myself, but for the interactive white board, we had this, there was a three-year programme for those people who donated the interactive white board in our school, so we normally go maybe three days, three to five days, two times in a year."* [T4]

The superficial knowledge of digital technologies imposes limited integration in teaching and learning. The environment is aggravated by teachers who depend solely on time-consuming self-directed learning (Calderón-Garrido et al., 2020) because of the fear of being left behind. However, strategically well-prepared training should be organised (Modelski et al., 2019) so that teachers experience teaching and learning activities aligned to the use of digital technologies for transformation of delivery of lessons. One participant mentioned:

> *"What I do think is that there should be short courses to engage that will help teachers on how to use these devices because I have realised that most teachers are struggling …"* [T6]

Not only the teachers, but:

> *"… also our learners need to be trained how to use those, … if there is an app that we can use to conduct online learning where they will require a password of something, they must be trained through all of these."* [T1]

For these participants, it is not only about having digital technology resources but also,

> *"… especially educators need to be educated about the importance of using this ICT"* [T4]

and this demonstrates the lack of the TK that teachers have. Since the rapid transition to online learning during COVID-19, teacher training in the use of digital technologies became a necessity (Van Greunen et al., 2021). As a result, a redefined teacher training model must be introduced that encourages learning anywhere, anytime (Valverde-Berrocoso et al., 2021).

Schools not only lack technology infrastructure but are also in need of more classrooms, electricity, and Internet. According to one participant:

> *"Our schools have a challenge of not getting enough classrooms. If you are planning to deliver with a projector, you are allowed to use the projector in a spare space like a storeroom."* [T5]

However, collegiality plays a significant role in learning to do something that would benefit a group. A few participants [T3; T5; T7] mentioned that they ask another 'young teacher' to assist if they need support. Another participant shed light in saying:

> *"We usually encourage a SMT member, we do encourage each other to use those stuff and those who do not understand how to use them we help them, we help each other, like especially on, yes, downloading videos, simple things like downloading videos and then I gather there are those teachers born before technology."* [T3]

In order to realise an effective utilisation of digital technologies in delivering and preparing lessons, a more sustainable and comprehensive teacher training system needs to be developed and should provide all teachers with the necessary technology and infrastructure knowledge (Beardsley et al., 2021). This training system also needs to be supported by the officials of the provincial departments and the South African Department of Basic Education [T5; T7].

6.3 Experience in using Digital Technologies

Integrating digital technology in teaching and learning is a challenge (Viberg et al., 2020) and was not found to be any different for the participants in this study. Similar to the findings of other studies (Abukhattala, 2016; Nikolopoulou, 2020), infrastructure remains a challenge. Participants mentioned that lack of electricity, Internet access, the limited number of devices and poorly resourced classrooms [T2; T3; T7], all impacted the teachers experience with regards to how they experience using digital technologies to enhance their lessons.

> *"Well I like to have an alternative, so sometimes when we are busy, playing the video, electricity will go off, so I like to have my alternative."* [T2]

Even if the school has a classroom with electricity and technology to use, preference is given to the Grade 10 to 12 learners, leaving Grade 9 teachers to continue without technology. However, in some cases, Grade 9 teachers did manage to use technology [T2; T4] even if they had to use their personal mobile phones or download videos at home so that the learners can watch it in class (Abukhattala, 2016).

> *"So, we do download video lessons and then send them when we are at home. We send them to their phones, while they are at home, they use them when they are at home, but when at school, it is not going to materialise."* [T3]

Irrespective of their attempts and opportunities to use technology, teachers still express that they need more support. Fortunately, some of the school's subject groups support each other [T3] or they have an IT champion (teacher proficient in technology use) that increased knowledge regarding technology.

> *"In most cases I ask someone who is well knowledgeable. Sometimes I use my phone to Google and get a solution."* [T5]

Teachers should be equipped with troubleshooting skills to avoid disruptions when using digital technologies in teaching and learning. A teacher should be aware that if the electricity goes off during a lesson, a surge protector can provide a stable current flow when electricity returns. According to an earlier study (Viberg et al., 2020), if teachers do not have knowledge of addressing the barriers to integrating digital technologies in teaching and learning, they struggle in making learners understand how they can learn from it as well as how to navigate the tools or a platform using instructions. Improving digital technology usage in schools can be done in different ways, ideally to provide a teacher with infrastructure and allow the learner to use it as deemed fit to achieve the learning outcomes (Kara & Cagiltay, 2017; Monteiro et al., 2021).

The three themes that emerged from the data is indicative of the role TK plays in the Grade 9 teachers' experience when integrating digital technologies in their classrooms. The participants shy away from using digital technology mostly because they do not have access to it, however, their lack of using it could not be contributed to the lack of TK. However, the majority of the teachers attended a limited number of training opportunities and that resulted in a lack of knowledge integrating digital technology resulting in them experiencing a series of challenges when attempting integrating digital technology on a limited scale. From the data it is evident that all three themes in one way or another relate to technology or the lack of using technology (TK). Not only is the use/no use of technology an issue for the teachers, they also lack the 'know how' to translate the content that they know in a way to incorporate technology and at the same time reach the learning outcomes. This 'know how' translates to the lack of TK.

7 CONCLUSION

This study explored the Grade 9 teachers' experience when integrating digital technologies in the classrooms. The findings revealed limited integration of digital technologies in delivering lessons making TK non-existent. The reasons for this vary from not having the technology available, lack of support, to not having the knowledge or 'know how' to integrate digital technologies. The minimal support provided to teachers and the challenges experienced as they integrated digital technologies in their lessons, resulted in less support to learners. The TK (construct of the TPACK framework) in the context of this study, not only highlights the importance of technology knowledge to integrate appropriate digital technologies in the classroom, but

mirrors the lack of digital technology integration. Teachers should understand the working of digital technologies in order to use them effectively in their classrooms.

Worldwide, the COVID-19 pandemic forced the rapid transition to technology integration and where possible, attempts to implement digital technologies (Ganimian et al., 2020). However, more than 50% of the learners in low-income countries and in poor surroundings were unable to participate, resulting in no learning opportunities for them. While one of the advantages of digital technology is to increase access to quality education (Valverde-Berrocoso et al., 2021), the pandemic highlighted the digital divide (Collie et al., 2018). All these initiatives are commendable, however, if a student does not have electricity, Internet access or data, this is of little value (Viberg et al., 2020).

Irrespective of all the challenges faced, some teachers did use digital technology, even if it was their own personal devices, to integrate digital technologies into their lessons. In this study, it was clear that when there is one teacher (champion) that uses digital technology, it encourages others to also use it, and it means that just-in-time support and encouragement is available (even on a limited scale) to other teachers. Also, the value of supportive school leadership is evident in the discussion with the participants as well as the need for continuous professional development opportunities. This study recommends that more research is conducted regarding the lack of pedagogical knowledge, and strategies planned to provide training opportunities for teachers on the integration of both technology and pedagogy knowledge to deliver their lessons.

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Research Article

Digitisation of higher education and research: Raising inclusivity and equity issues for indigenous students

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ABSTRACT
This conceptual article critiques digitisation of higher education and research as it relates to inclusivity and equity for indigenous students. I argue that indigenous students' access to education is not limited to indigenisation of their learning, knowledge and research; it is more about what they learn and how they learn it through technology – information and communication technology (ICT) and online platforms. These students are excluded and do not enjoy equal educational opportunities when digitising their learning and knowledge does not relate to their cultural contexts. In addition, innovative projects and programmes which are insensitive to the dynamics of indigenous knowledge further make indigenous knowledge vulnerable to colonial practices. This article contributes insights into the vulnerability of indigenous students and institutions of higher learning being uncritical of the digitisation of their learning, knowledge, and research. The article will conscientise institutions of higher learning to digitise learning and research from a truly transformational perspective.

Keywords: Digitisation, higher education, inclusivity, indigenous students, indigenous knowledge.

Categories: • *Applied computing* ∼ *Education, Computer-managed instruction*

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1 INTRODUCTION AND PROBLEM STATEMENT

Digitisation of higher education, especially teaching, learning and research is on the increase. Therefore, digitisation is revolutionising higher education. The Fourth Industrial Revolution (4IR) and the outbreak of the Covid-19 pandemic have added to the fast-tracking of digitising of education and research (Alnagrat et al., 2022). For instance, the Covid-19 lockdown regulations forced people to convert to virtual operations. Both academic staff and students in higher education institutions had to operate from home. Higher education institutions are faced with the demands to transform into technological hubs and be 4IR savvy (Telukdarie & Munsamy,

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2019). For this to happen, higher education institutions should be equipped with information and communication technology (ICT) for effective teaching, learning and research (Borrero, 2013; Sharma et al., 2011).

The literature raises issues about digitisation of higher education provisioning (Strathman, 2019), such as changing the identities of academics (Dlamini, 2017) and institutional operations and architecture (Telukdarie & Munsamy, 2019). Talks at conferences and seminars herald the positive side of the digitisation of student learning. However, the impact of digitisation on indigenous students has been neglected, raising issues of their inclusion and equality. Digitisation has eased teaching, learning and research through by creating online platforms. However, technology is not yet responsive to all students' needs. Thus, the aim of this literature study is to critique digitisation of learning and research in the higher education institutional context in reference to inclusivity and equity for indigenous students. Indigenous students do not truly feel included and treated equally in the digitisation of education and research. This means that an effort should be made to include not only them but indigenous knowledge and pedagogies. Indigenous students are described as belonging to communities that are original inhabitants of a certain geographical region or country before the colonisers arrived. Indigenous communities have distinct characteristics such as culture, beliefs, language, history and technology compared to the colonising culture.

In the light of the positive side of digitisation of education mentioned above, there is a promise to increase access, shorten the distance between the lecturer and student, promote meaningful learning, etc, especially for indigenous students who have been historically marginalised (Glover et al., 2018; Makhanya, 2021; Pratt et al., 2018). In the postcolonial era in South Africa, there is a promise to include indigenous students by increasing their access to education through ICTs (Heleta, 2016). ICTs provide resources through which digitised education can be provided. Hence, digitisation and ICTs are used interchangeably in this article. However, the inclusion of indigenous students can be effectively achieved by enacting the human rights that are encapsulated in the National Constitution, and policies that promote indigenous knowledge, such as the Indigenous Knowledge Systems Policy (Department of Basic Education, 2011); the Curriculum and Assessment Policy Statement Grades R–12, which is framed within the seven principles, i.e. social transformation; active and critical learning; high knowledge and high skills; progression; human rights, inclusivity, environmental and social justice; valuing indigenous knowledge systems; credibility, quality, and efficiency (de la Porte & Higgs, 2019). Hence, higher education institutions should be sensitive toward students whom they receive from schools, who are informed about human rights. Also, the Africanisation of the curriculum project in higher education institutions suggests that digitisation of learning and research should not compromise indigenous knowledge.

Indigenous knowledge is still vital in modern times; it is however not sufficiently recorded with relevant ICTs for future use (Department of Science and Technology, 2004). In Australia, for example, cultural materials designed for Anglo Australians were found pedagogically inappropriate for indigenous Australians (South Africa, 2004). ICT programmes have been criticised for their skewed function to impose Western processes on indigenous people,

creating computer-mediated colonialism (Borrero, 2013). It is, therefore, important that while higher education institutions digitise their academic project, they should not compromise the inclusion of indigenous students, knowledge, and pedagogy. This is because indigenous people as both stakeholders and rights holders are increasingly the focus of the ongoing discussion about the positive and negative aspects of ICT, and the possibilities of information and communications-based transformation (Borrero, 2013, p. 1).

The impact of ICTs on educational access is one of the three challenges in the Draft White Paper on e-Education (South Africa, 2004). The challenges are attributed to globalisation and polarisation (rich and poor) (South Africa, 2004). For instance, the Draft White Paper records only 6.4% of South Africans who use the Internet compared to 72.7% of Americans (South Africa, 2004). The Draft White Paper also acknowledges that the digital divide is not only about connectivity and infrastructure disparities but local content development and collective knowledge generation as well, thus confirming the fact that the inclusion of indigenous students should be extended to indigenous knowledge, pedagogy, and research. The New Partnership for Africa's Development (NEPAD) identifies ICTs as the promising solution to reduce poverty on the African continent in which ICT-proficient youth and students can be produced as engineers, programmers, and software developers (South Africa, 2004). There is therefore an intention to implement ICTs that are specifically suited to Africa, through appropriate technologies (South Africa, 2004). Inspired by human rights, the use of ICTs should encourage student-centred learning; active, exploratory, inquiry-based learning; collaborative work among students and lecturers; creativity, analytical skills, critical thinking, and informed decision-making (South Africa, 2004). NEPAD's huge investment in this project might fail to provide sustainable solutions if the project cannot consider the youth's local knowledge and practices. The next section describes the working concepts in this article.

2 CONCEPTUALISATION

2.1 ICTs and digitisation

As stated above, ICTs provide resources for the digitisation of education. Viewed as digital technology, Pettersson (2017) defines ICTs as the information technologies which promote access to education. They include the new wave of ICTs which covers Internet-based communication and transaction systems, mobile devices, computer-integrated telephones, groupware, workflow, and multimedia (Sarker et al., 2019). "ICTs are the combination of networks, hardware, and software as well as the means of communication, collaboration and engagement that enable the processing, management, and exchange of data, information, and knowledge" (South Africa, 2004, p. 15). Web 2.0 applications such as wikis, weblogs, social networking, podcasts, and RSS feeds (Watson, 2013) are some of the digital platforms which are created through ICTs to enable such communication, collaboration, and engagement. ICT is also viewed as the scientific-technological and engineering discipline and management technique, and it is used in the handling of information in application and association with social, economic, and

cultural aspects (Sharma et al., 2011).

Pettersson's (2017) definition is most suitable for discussions in this article as it spotlights the reflections on the digital divide. It is in this light that besides student access, digital divide has created Internet access issues. I argue that even proper Internet access is not an end in itself but a means to an end; it should be more about the content which is conveyed to the students and how. ICTs may do well to provide full access to information and knowledge sources (Sraku-Lartey et al., 2017), but they not only do that; rather, they should help promote indigenous perspectives instead of advancing non-indigenous perspectives only. If epistemological and pedagogical issues related to indigenous knowledge are not raised, ICTs could perpetuate colonisation, thus compromising the Africanisation of education projects. The use of ICTs in education should help with the decolonisation project. This raises the need to describe decolonisation.

2.2 Decolonisation

Decolonisation refers to an action of combating the colonial status in favour of independence. Educationally, this means changing the mind, personality, social actions, education settings, curriculum, and research practices (Hart, 2010) among other things. Decolonisation means the historically colonised people freeing themselves from their colonial status to independent status. In academia, the researcher and research should be decolonised (Datta, 2017). This claim is informed by the fact that higher education institutions thrive on research, which frames their academic programmes. However, decolonisation needs rethinking and taking action, especially, in the context of this article, curriculum and research. The South African students' #FeesMustFall campaigns around 2015–2016 were about affordability and access to education, but most importantly, the students also called for indigenisation of the curriculum and pedagogy in higher education. A decolonisation and digitisation process model would ensure fair treatment of all in the country and the continent. The current study focuses on education.

2.3 Indigenous knowledge

Indigenous knowledge is commonly community-held (local) knowledge that involves detailed and shared knowledge, beliefs, and rules related to the physical resources, social norms, health, ecosystem, culture, the livelihoods of the people who interact with the environment both in rural and urban settings (Gumbo & Karel, 2020; Sraku-Lartey et al., 2017; Sukula, 2006). This knowledge is inherently tacit and uneasy to codify, and it resides in community practices, institutions, relationships, and rituals, which might be the reason why it suffers marginalisation by modern scientific knowledge (Sukula, 2006). It may be understood in terms of different fields, but it is integrated due to indigenous people's holistic approach to knowledge construction and practices. It sustains the lives of indigenous people in a particular environment. Indigenous students must primarily be taught about this knowledge. Non-indigenous students can

also benefit by being exposed to indigenous knowledge as an alternative knowledge to Western knowledge – points of contact between these two knowledge types can also be explored through learning and research.

The characteristics of indigenous education include observational learning which augments verbal learning; experiential learning which augments listening; and learning settings which are contextually meaningful (Watson, 2013). Hence, it is important to relate learning to students' contexts, authoritative knowledge by elders, the educational role of elders and other indigenous practitioners, indigenous people's ways of doing things, group solidarity, acquisition of knowledge directly from the expert in an apprentice-novice system, fusion of emotional and intellectual domains (Watson, 2013). In addition, there are seven principles of indigenous worldviews that academics should consider:

1. the nature of knowledge as holistic and cyclic, which depends on relationships and connections to living and non-living beings and entities,
2. multiple truths which depend on individual experiences which culminate into a community knowledge,
3. everything is alive,
4. all things are equal and should thus be respected,
5. the land is sacred and this deepens contextual attachment to it,
6. the relationship between people and the spiritual world is important,
7. human beings are least important in the world (Gumbo & Karel, 2020, p. 3).

Consideration of these characteristics and principles would help transform education, and indigenous students would see the value of partaking in learning and research as they would relate to the students' contexts and cultures. Thus, digital environments should be designed with cultural adaptability in mind in order to include all students (Watson, 2013, p. 14); this can help not to limit digital environments to digitisation only. The discussion in the next section turns to the digitisation of students' learning while keeping to the line of thinking on indigenous students.

3 DIGITISATION OF LEARNING FOR STUDENTS

Digital pedagogy promises to deliver effective learning to students (Salavati, 2016). It is for this reason that digital pedagogy is heralded for increasing student performance, eliciting student engagement, and defacing boundaries between learning and socialising (Watson, 2013). Digitisation of learning, therefore, promises to promote indigenous students' access to education, research, and indigenous knowledge. I also argue that digital learning has the potential to decolonise education and accommodate the indigenisation of the academic project.

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When indigenous knowledge is accorded the respect that it deserves through digitisation of learning and research, it can encourage students to want to know more about it. To illustrate this point, I draw on North-West University's attempt to digitise education and research. Research students engaged in the Tswana indigenous pathways to health in collaboration with the Department of Health in the province. These students used multimedia technology to document community health practices. Thus, the task enabled interaction between the students and knowledge holders. Also, the use of technology encouraged the community project method which balanced theory and practice and encouraged the use of the local language. Elders and practitioners were regarded as important participants in knowledge sharing. They were also invited during lectures to share knowledge with the students. This approach to student learning can help address the elders' concerns about the youth who are growing up losing their true indigenous identity and lacking the understanding of community knowledge traditions (Gumbo, 2020; Strathman, 2019).

Digitisation of higher education is almost mandatory for students and academics in the current era. This must, however, be accompanied by a decolonisation agenda. Implied in this statement is the need for proper treatment of indigenous knowledge so that it is valued like other types of knowledge, and that indigenous students should feel that they do fit in the learning situation. Young people are technology activists and natives; this provides an excellent opportunity to make both indigenous and non-indigenous students learn about indigenous knowledge. It is argued that professors limit the description of the world to Eurocentric contexts and ignore indigenous perspectives and understandings (Gumbo & Karel, 2020). This exposes both indigenous and non-indigenous students to a narrow (Western) knowledge and denies them opportunities to learn about indigenous knowledge. It is claimed that marginalisation of indigenous people has been and continues to be a colonisation tool (Gumbo & Karel, 2020).

The digital misrepresentation or underrepresentation of indigenous knowledge has been observed in the massive open online courses (MOOCs). This raises critical epistemological questions related to MOOCs:

- Where do the content and technology that support MOOCs come from?
- Who controls knowledge?
- What knowledge do students learn?
- Whose knowledge do these students learn and how?

Furthermore, research, teaching, and learning material heavily depend on Western academic systems and are accompanied by the dominance of literature and articles published in influential journals (Altbach, 2014). If the academic (teacher) does not ask epistemological questions such as these, he/she would add to the marginalisation of indigenous knowledge by high-profile universities. Such an academic's uncritical attitude will only satisfy certain establishments, such as major academic journals, editors and editorial boards, and big academic

publishers which reside in the global centres of knowledge such as Boston, New York, and London (Altbach, 2014). It should be noted that modes of inquiry that are related to Western traditions are not the only available options (Altbach, 2014). Indigenous knowledge offers an alternative to such traditions.

Language also plays a big role in the digitisation of knowledge and research. In this sense, English remains to be the language of learning, research, and knowledge dissemination. There is insensitivity to other languages and major academic websites are packaged in English only, disadvantaging indigenous languages and students ultimately. Language cannot be divorced from culture as it is a tool for cultural expression. We can learn from the ICT department of Ethiopia, which has found a way to programme the local language alongside English in gadgets such as cell phones. The logic of this claim is that learning which happens through English perpetuates Western culture. A lot of digitised information is only available in English. There is a need to give equal status to all languages in accordance with South Africa's language policy. Digital transformation of education should promote indigenous languages so that indigenous students are not further disadvantaged in their learning activities. As a matter of fact, the meaning of some indigenous expressions cannot be completed through English, the obvious ones being adages that can provide educational resources for indigenous people. The next two sections are critical as they highlight the positives and limitations of digitisation of indigenous knowledge. Attempts to digitise indigenous knowledge elsewhere help in the discussion.

4 DIGITISATION OF RESEARCH ABOUT INDIGENOUS KNOWLEDGE

The ICTs can be used in a way that ensures the preservation of indigenous knowledge and the prevention of its possible extinction. Preservation, access, and wider dissemination of indigenous knowledge (Sraku-Lartey et al., 2017) can therefore be realised through digitisation. Strathman (2019) examined indigenous heritage projects produced by university researchers between 2002 and 2007 in collaboration with indigenous communities, by investigating issues that arose ten years after their production. Strathman's (2019) choice of projects was informed by the academic activism which produced them through participatory action research (PAR). PAR is regarded as engaged scholarship and a decolonising method of giving back to the indigenous communities (Strathman, 2019, p. 3722). Data was mainly collected from the respective scholars and source communities. Academic activists hereby referred to as 'technological missionaries' (Strathman, 2019), shared their technological talents by collaborating with indigenous communities in planning, using, and developing the ICTs.

In the above projects, the academics wanted indigenous communities to install and maintain the equipment themselves because they (academics) focused on sustainability (Sandvig, 2013). Indigenous people who have access to the ICTs used digital media to share their tangible and intangible culture and store their vast bodies of knowledge (Steeves, 2015; Strathman, 2019). The academics shared their technological talents by collaborating with indigenous communities in planning, using, and developing ICTs (Strathman, 2019). From the projects, most (postgraduate student) researchers made the creation of a digital heritage pro-

gramme part of their theses. The author cites Delgado, who records that every summer season, many North American and European students who possess computer skills head south to work with indigenous organisations.

Strathman (2019) further reports on a project of Braun, who founded the High-Performance Wireless Research and Education Network in San Diego. Intending to make indigenous communities the owners of the project, Braun included tribal communities as beneficiaries of Internet access when he drafted his grant proposal and allowed them to learn how to install and maintain the equipment. The native technicians designed and built the 23 solar-operated relay towers which extended wireless broadband coverage across 600 miles of tribal lands to form a Tribal Digital Village. Involving indigenous people in the digitisation of indigenous knowledge could strengthen its protection against unauthorised people wanting to claim its ownership. It can also be protected from bio-piracy and expropriation, especially by multi-national companies (Sraku-Lartey et al., 2017). However, it should be ascertained whether the communities have the ability to continuously guarantee ownership and integrity of their knowledge and that its sacred features would not be disturbed (Sraku-Lartey et al., 2017), especially considering the fact that indigenous knowledge is not easy to codify (Sukula, 2006).

A study on the digitisation of indigenous knowledge of forest foods and medicine was conducted in Ghana using open-source software (Sraku-Lartey et al., 2017). The aim was to promote Ghana's forest resources and to unearth the hidden treasures of the forest from which these resources were obtained (Sraku-Lartey et al., 2017). A key recommendation that these authors made is to promulgate laws that will protect these resources from bio-piracy. Locally, digitisation of the cultural heritage was investigated, and the results revealed that open access to digitised cultural heritage material was encouraged, but access to its use was limited (Verran, 2009).

These reported projects offer the positive sides of the digitisation of indigenous knowledge, which can be packaged for learning and research. The active involvement of indigenous communities – to decide and determine what can and what cannot work makes the digitisation of knowledge relevant for them, especially students who must learn from it and feel included. As can be noticed, research projects help to create a platform for packaging and learning about indigenous knowledge. This is not possible if the researcher and research are un-decolonised (Chilisa, 2012; Datta, 2017). Thus, a paradigm shift is invoked to ensure the indigenisation of research (Gumbo & Karel, 2020):

Ontology should recognise the spiritual realm which is interconnected with the physical realm since indigenous science integrates a spiritual orientation that honours human relationships with other life. Hence, researchers who research indigenous knowledge are bound to accept the triple relationship between humans, nature, and spirituality. All life must be respected since humans are in reciprocal relations with everything that exists.

Epistemology is a fluid way of knowing that derives from teachings transmitted from generation to generation by storytelling; it arises from the interconnections between the human

world, the spirit, and inanimate entities; it is undergirded by perceptual experiences about self in connection with the happenings which are facilitated through rituals/ceremonies (e.g. dreaming, visioning, meditation, and prayer) of which the ultimate is the knowledge with the elders and practitioners playing the educational key role.

Methodology should engage participants actively throughout the research process. Hence, methodologies such as PAR are preferred (Chilisa, 2012). It is argued that for the genuine representation of participants' voices, they should participate even in data analysis (Datta, 2017). The researcher should ensure his/her relational accountability about the dynamics of the research site and participants, noting that knowledge is relational, i.e. it is shared with all creation (e.g. cosmos, animals, plants, earth), is practical, i.e. indigenous people create knowledge because they want to use it.

Axiology in which the researchers should recognise that indigenous knowledge is undergirded by values, principles, and ethics. This includes but is not limited to the custodians who develop, approve, and implement research; respect for individuals and communities; reciprocity and responsibility; respect and safety (e.g. being open to participants' preferences about concealing or revealing their personal information such as names); non-intrusive observation; deep listening and hearing; reflective non-judgment; honouring what is shared; awareness and connection between the logic of the mind and feelings of the heart; self-awareness; subjectivity.

In light of this paradigm shift, three concepts are considered which could reorientate innovative projects which target indigenous communities (Borrero, 2013):

1. pro-indigenous (i.e. for indigenous peoples) in which external innovations to the target communities are undertaken on behalf of indigenous peoples,
2. para-indigenous (i.e. with indigenous peoples) in which innovations are undertaken alongside indigenous peoples,
3. per-indigenous (i.e. by indigenous peoples) in which innovations by indigenous peoples are based on their own self-defined needs and wants.

The projects described above would fall under para-indigenous because they were designed with indigenous people. PAR can actually make indigenous people take a lead in the projects introduced to them. Following PAR, proper fact-finding should be conducted first to identify the needs/wants/issues. Then, with proper facilitation by the researcher(s) concerned, indigenous people should be asked to suggest solutions that they can create themselves. They can be trained in computer skills, but they should take the lead in what they package and how. The parallel scenario which pertains to learning is that students should be allowed to relate learning to their contexts.

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5 LIMITATIONS OF DIGITISATION OF INDIGENOUS KNOWLEDGE

No doubt, digitisation has contributed to the development of underdeveloped contexts, especially with regard to access to education, but it has also furthered marginalisation of indigenous people. The very ICTs which are praised for student access to education and digitisation of indigenous knowledge are notorious for heightening the vulnerability thereof, as well as learning, and research. Though the need for teachers to be abreast with the latest technological developments is emphasised so that they have expert technological pedagogical and content knowledge (TPACK) (Mishra & Koehler, 2006), they still present themselves with inadequate ICT skills (Watson, 2013). TPACK, which is ICT-dependent would have to be indigenised. How this can be done is illustrated through the proposed framework described in Section 6.

Technology also attracts issues about the use of digital resources to preserve knowledge, which includes affordability, simplicity of its use, security, and privacy, and reliability of access to electricity (Steeves, 2015; Watson, 2013). In South Africa, for years there have been power cuts and load shedding. Rural people the majority of whom are indigenous communities are the most affected by this issue. Digitisation and ICT do not show equal distribution considering the rural and township nature of the country. As a result, the cost, sustainability and efficient utilisation of ICTs has generally remained a problem (South Africa, 2004).

Furthermore, the "deployment of ICTs does not guarantee their efficient utilisation. Capacity building and effective support mechanisms must accompany deployment" (South Africa, 2004, p. 10). ICT-related inequality that is exacerbated by digitisation is prevalent in South Africa. This is evident in the two main challenges that students who come from poor contexts face, which are lack of access and exclusion of their knowledge. Indigenous knowledge is left out in the attempts to reverse this situation. Thus, indigenous knowledge access and promotion problems still remain despite attempts to deface them through the involvement of ICTs in education. ICTs receive emphasis with fewer debates about what knowledge should be digitised and how it should be treated.

ICTs are like a truck that delivers goods; the focus should be more on the goods themselves. What this means is that ICTs harbour the content, modes of delivery, and educational processes, which need to be checked against cultural representations. Online learning should be balanced with these important aspects. The digitisation project should be decolonised to realise fair treatment of indigenous students. The rural-urban digital divide that is propelled by ICTs should be scrutinised. This is because the problem is not only about the digital divide but knowledge delivered by the ICTs 'truck' – whose knowledge is in the 'digital truck'? What are the effects of this knowledge on indigenous students?

There are security issues presented by ICTs as well. In one project, Strathman (2019) collaborated with the Warumungu – an Australian indigenous community. The Warumungu suspected the abuse of its local knowledge by digitisation, and therefore did not want its digital archive to be online to secure the information (Strathman, 2019). In other cases, the content was shared online as virtual exhibitions as a measure to prevent its possible loss and ill-treatment. Equally, the ownership of the created content on the media which is disseminated

via the World Wide Web for educational purposes is a concern for indigenous students (Watson, 2013). Knowledge holders' lack of ICT skills (Department of Science and Technology, 2004) may raise ethical issues as researchers or digital archivers may take advantage of the ignorance of the knowledge holders.

Added limitations relate to resources (especially funding) needed to upgrade the computers which were used to archive indigenous knowledge as they became outdated. While grants may be available for the establishment of a new site or system, there might be no help to refurbish or update it; indigenous communities have mostly depended on relationships with researchers, universities, and non-governmental organisations to develop ICTs. Strathman (2019) cites another case, i.e. a computer program called TAMI (Text, Audio, Music, and Images) which has been faithful to the principles and practices of indigenous production. It is described as a completely fluid file management and database system free of Western assumptions about knowledge or ecology, and which enables the user to creatively relate and annotate assemblages of resources for his/her own purposes (Verran, 2009, p. 178). However, for enamoured scholars with indigenous knowledge, collaboration may become a disguised colonial whitewash that promotes co-optation and dependence (Hutchings in Strathman (2019, p. 3732)), a thing that must be avoided.

6 TRANSFORMING DIGITISATION OF EDUCATION AND RESEARCH

Digitisation of education and research in higher education can be transformed if there is no compromise of indigenous knowledge. Programmes that are parachuted (pro-indigenous) into the university curricula should observe the dynamics of indigenous knowledge before any attempt to digitise and teach it. There should be a commitment not to emphasise digitisation at the expense of indigenous knowledge. This can be realised only if the peri-indigenous approach in which indigenous knowledge holders take the lead can be adopted. In the teaching situation, the lecturer should learn along with students by allowing them to share and co-construct knowledge and research the phenomena that are engaged in their learning. Students, as members of their communities, bring into the lecture rich local knowledge which can make their learning meaningful and relevant to their cultural contexts. An indigenous-nonindigenous technological pedagogical and content knowledge (INDNONIND-TPACK) (Glover et al., 2018) is suggested as a framework that can balance the content and pedagogies from indigenous and Western contexts that are delivered by the "digital truck". Proper treatment of indigenous knowledge can help demonopolise Western knowledge, pedagogy, and research. It can also benefit both indigenous and non-indigenous students by creating equal opportunities for learning and doing research. The non-indigenous students have been presented with a narrow view of knowledge and deprived of the opportunity to learn about their own knowledge systems. Points of convergence and divergence between indigenous knowledge and Western knowledge could be explored through learning and research as part of decolonising digitisation and knowledge in higher education. Figure 1 shows how this could be done. Students can be teachers to one another, especially with particular reference

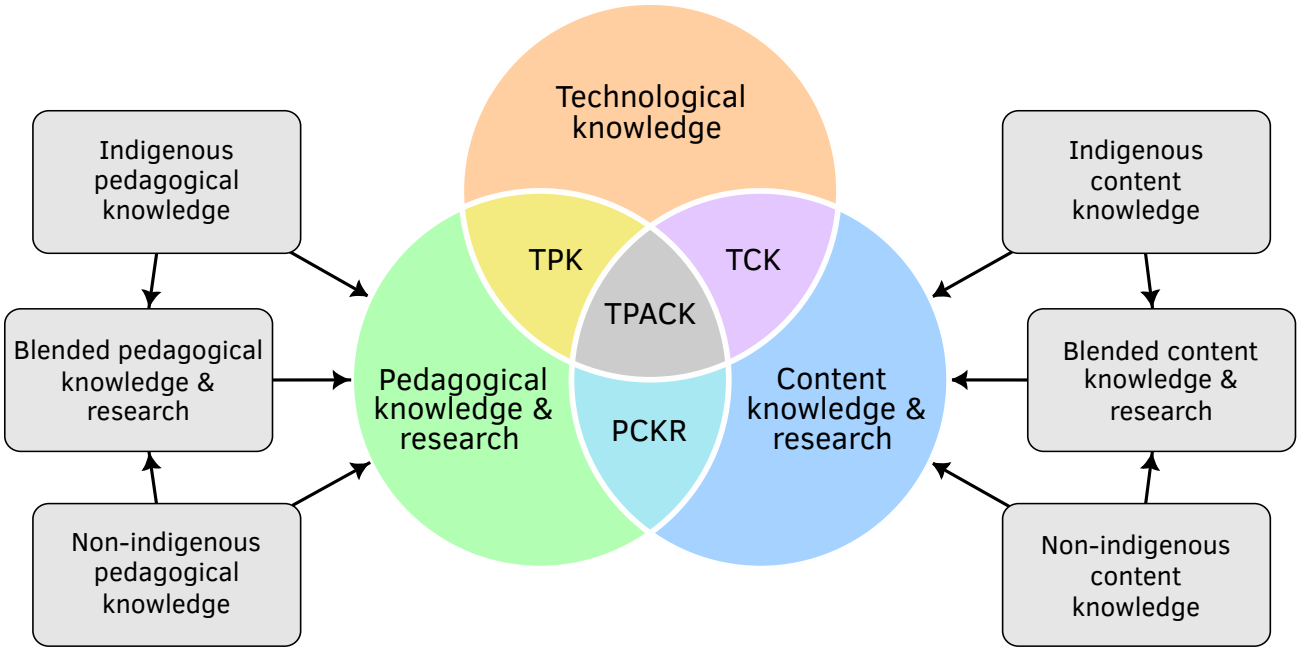

Figure 1: INDNONIND-TPACK[a]

[a]adapted from Department of Science and Technology (2004)

to indigenous knowledge which non-indigenous students do not know much about.

The technological pedagogical and content knowledge framework carries the idea that technology can be used to load and present the content (packaged from knowledge) to students. INDNONIND-TPACK presents the transformational version of TPACK. It shows the two knowledge, pedagogy, and research worlds (Western and indigenous) from which to draw similarities and differences so that both indigenous and non-indigenous students can have equal opportunities to learn about knowledge that relates to their cultural contexts.

7 CONCLUSION

A clear concept of ICTs/digitisation should be established in higher education to ensure the non-discrimination of indigenous students. A central argument in this article is digitisation of student learning and research in higher education as they relate to inclusivity and equity. Critical views are provided on the topic. The article contributes insights into the further vulnerability of indigenous students and knowledge which can be created by the uncritical digitisation

of learning, knowledge, and research in higher education. I, therefore, propose that:

1. curricula should be truly transformed to make them relevant not only to non-indigenous students but to indigenous students as well;
2. there is, therefore, a need to balance indigenisation of curricula with digitalisation – it is not only about training students to be digital-savvy but more about what they learn and how technology is used in their learning and research activities;
3. inclusion and equal opportunities for indigenous students are matters of decolonisation which should penetrate digitisation of education and research.

This will establish an effective foundation for decolonised education and research (Salavati, 2016). It is insufficient to train today's students as digital activists and natives only. Instead, institutions of higher learning should integrate ICTs without compromising decolonisation.

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Research Article

Exploring ideological-ware as a resource in the use of Moodle in higher education – analysing Covid-19 publications

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ABSTRACT

Across the globe, the advent of the coronavirus disease (Covid-19) has propelled most sectors to do their business online. Higher education institutions (HEIs) in particular have had to move their teaching and learning online, with Moodle (modular object-oriented dynamic learning environment) reported to be one of the most used platforms internationally. In the context of Covid-19, educational researchers and publications have discussed various ways in which this platform has influenced the three types of curricula, namely: competence curriculum; pragmatic curriculum and performance curriculum. However, there is less emphasis on ideological-ware in the use of Moodle as a teaching and learning resource, which presents a serious challenge and requires systemic debate and reflection. This study uses critical discourse analysis and community of inquiry through purposive and convenience sampling to identify the published documents on the use of Moodle as a teaching and learning resource in the context of Covid-19. Findings indicate that most scholars are advocating that the successful use of Moodle in higher education institutions relies on ensuring that hardware and software resources are available for both lecturers and students. This suggests that HEIs are focusing on the performance and competence-based curriculum, yet limited mention is given to ideological-ware as an important aspect when using Moodle.

Keywords: Higher education; Moodle; ideological-ware; Covid-19; competence curriculum; pragmatic curriculum; performance curriculum

Categories: • *Applied Computing* ∼ *Education, e-Learning*

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1 INTRODUCTION

The advent of Covid-19 forced changes in the curriculum systems of higher education institutions across the globe, including developing countries such as South Africa. The changes brought about migration from traditional methods of teaching and learning to online learning. Although many HEIs were accustomed to online learning, Covid-19 drastically enforced

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changes that needed immediate implementation as there were few other alternatives to continue with effective teaching and learning. Online learning refers to the use of information and communication technology to deliver lectures and share instructional materials (Hassan et al., 2021). As the transformation to online learning took place, a number of articles were published on this required migration instigated by Covid-19. The publications focused on the impact of Covid-19; migration to remote learning; learning opportunities presented by Covid-19; digitalised curriculum; virtual classes, among others.

However, no reviews were found on ideological-ware resource in the use of Moodle in higher education in the context of Covid-19. According to Khoza (2018) ideological-ware resources are ideas, theories and thoughts involved in the use of technological resources when teaching. Ideological-ware resource remains significant in the process of teaching in the sense that these are teaching and learning strategies whereby the facilitator imparts ideas and pedagogical knowledge on the subject matter.

Consequently, without ideological-ware, the teaching and learning process cannot take place. Even though hard-ware resources such as computers; laptops; tablets; overhead projectors; cellphones, etc. may be available, they still require software resources to operate. These soft-ware resources include the internet, videos, and different apps that are used for teaching and learning. However, it is necessary for the teacher to have ideological-ware resources which are ideas and methods on how both these resources can be successfully used to fulfil the role of teaching and learning (Budden, 2016). Amory (2010) correctly argued that teaching is not only about hard-ware or soft-ware resources but is about ideology. Correspondingly, Shulman (1987) shared a similar understanding using a concept of pedagogical comprehension and reasoning, stating that it is essential for successful teaching. In a similar manner, Khoza (2015) disclosed that a curriculum that is driven by hard-ware resources to achieve its aims addresses the needs of the subject content and those of the community as well, whereas a curriculum that is driven by ideological-ware resources addresses the needs of the teacher and student.

Notwithstanding the successes of Moodle in ensuring continued learning despite difficult times, there are yet challenges that need attention. The central challenge faced by lecturers (especially those without previous experience of e-learning) is adapting to new teaching approaches involving the use of technology in their practice. Correspondingly, Mpungose (2017) identified that another challenge could be students not welcoming these new changes which could cause a barrier for students. Furthermore, there could be other obstructions with the infrastructure such as lack of hard-ware and soft-ware resources. Finally, there could also be barriers on the institutional leadership which could engender lack of support.

2 MATERIALS AND METHODS

Reviews specifically about exploring ideological-ware as a resource in the use of Moodle in higher education - analysing Covid-19 publications, were not found on Google Scholar and JStor. Nonetheless, there was one identified review by Khoza et al. (2021) *'Exploring the mi-*

gration to a digitalised curriculum at UKZN'. Even though this review highlighted the essence of ideological-ware, its main focus was on migration to a digitalised curriculum specifically at UKZN. This indicates that there is still a greater need for a study that examines, on a broader scale, digitalised curriculum ideological-ware resources used by HEI academics in teaching during the COVID-19 pandemic. Moreover, when keywords such as 'ideological-ware and Covid-19' were used in the search, several articles by Khoza, Mpungose, Makumane and Nhlongo were listed. These articles commonly advocate for the awareness and importance of performance, competence and pragmatic curriculum, and aligning the curriculum with resources (hard-ware, soft-ware and ideological-ware). It is important to note that even though they are relevant and can be used to generate data to advance this study, they cannot be classified as reviews since they are empirical studies. Thus, this scarcity of reviews on ideological-ware as a resource in the use of Moodle in higher education during Covid-19 presents an opportunity for this study to prevail.

3 CONCEPTS AND DEFINITIONS

In the context of this study, higher education institutions (HEIs) refer to organisations such as universities, colleges, and other professional schools that provide post-secondary education or training with a reward of a degree, diploma, or certificate at the end of the course. These institutions enforced digital transformation to complete the curriculum, since global closure of schools was part of measures to maintain social distancing to curb rapid transmission of Covid-19 (Khoza et al., 2021). The pandemic led to the migration from face-to-face methods to online methods of teaching and learning. The Moodle platform was one amongst many learning management systems (LMSs) used by HEIs to create lessons, manage courses, and facilitate lecturer-student interaction (Tang et al., 2021). Moodle is an open-source software online educational platform that provides custom learning environments for lecturers and students. However, to successfully utilise Moodle, the user needs to have hard-ware (physical gadgets), soft-ware (internet, programs, systems to control the hardware) and ideological-ware resources. According to Khoza (2016) ideological-ware refers to any component of one's teaching/learning that cannot be seen or touched such as thoughts, ideas, and experiences that facilitate teaching and learning.

4 DATA COLLECTION

4.1 Collection and analysis of selected papers

The authors of the study were responsible for the selection, collection and analysis of articles and other publications. All the articles and publications found on the search engines such as Google Scholar, ERIC (Education Resources Information Center), iSEEK Education and Science.gov, were verified for authenticity. The identified publications were documented and saved to be further analysed. The utilised publications were cited and referenced accordingly.

4.2 Selection criteria for publications

Both qualitative and quantitative publications and studies that were made and conducted during the Covid-19 pandemic which are aligned with exploring ideological-ware as a resource in the use of Moodle in higher education were included. The rationale behind this was to generate insight into the existing literature as well as to collect data. Studies, reviews and publications that were about e-learning but conducted prior to Covid-19, were excluded. Furthermore, studies that were published in languages other than English were also excluded.

5 FRAMEWORK FOR THIS STUDY

Figure 1 illustrates the framework of this study, identifying three categories of curriculum, namely competence, pragmatic and performance curriculum, that are aligned to three categories of experiences, namely shared-experience, self-experience and specialised-experience. The concepts of shared-, self- and specialised-experiences are the curriculum concepts pro-

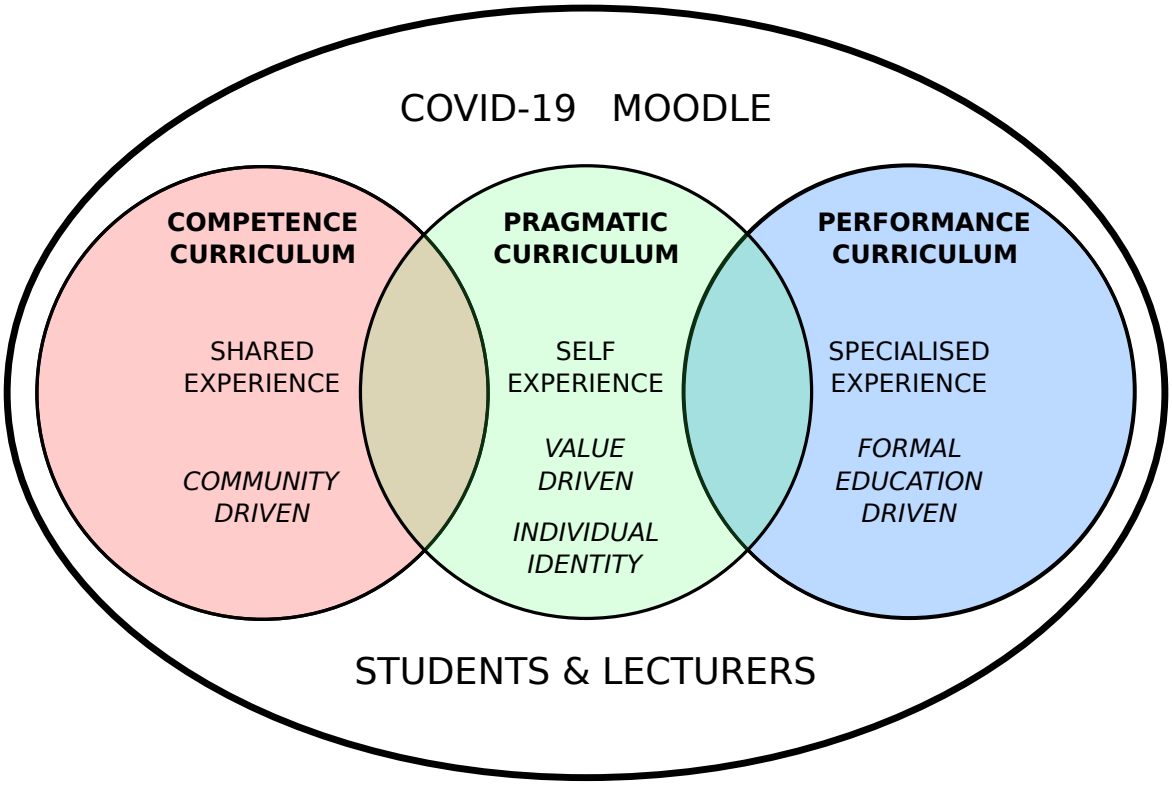

Figure 1: Three categories of experience aligned to curriculum.

posed by Zuma (2019). The meaning of shared-experience is derived from the word sharing which can be practised by the community. Self-experience is derived from individual identity,

in a sense that even if human beings can live in a community, each human has a different character, therefore the curriculum must accommodate and acknowledge the uniqueness of the student. Lastly, specialised-experience is derived from the word specialisation, in a sense that the needs of the curriculum are independent, whereby content shapes the individual identity of a student in order for the student to achieve global standards of a particular subject or module.

The discussion in the following sections will demonstrate how shared-, self- and specialised-experiences are aligned with competence, pragmatic and performance curriculum.

5.1 Shared-experience aligned to competence curriculum

Shared-experience means placing the needs of the community at the centre of teaching and learning (Khoza, 2015; Khoza et al., 2021; Mpungose, 2017). This suggests that teaching and learning addresses the community's needs, which is why the community is more concerned about the outcomes of the curriculum over aims and objectives. Similarly, competence curriculum prioritises learning outcomes for the students, whereby the students are active in their own learning and lecturers are facilitators (Khoza, 2015). To achieve these learning outcomes the lecturer guides and facilitates, and students may be given several opportunities to complete or resubmit their assessment tasks until the desired outcomes are achieved. In addition, students are encouraged to participate in peer-assessments where they offer constructive criticism to each other's tasks to an extent that they get marks for critiquing (Zuma, 2019). This illustrates that competence curriculum is based on sharing experiences, through which the knowledge, skills, ideas and opinions of others are valued and used to drive the lesson.

5.2 Self-experience and the pragmatic curriculum (blended learning)

Self-experience, is a recognition of the student's or lecturer's individual identity within the curriculum (Zuma, 2019). At this level, lecturers are using the correct ideologies to support students. Self-experience recognises that the teaching and learning process is about individual identity, capabilities, strengths and talents (Leroux & Levitt-Perlman, 2010). Therefore, individual uniqueness and identity are central in any activity of teaching and learning taking place inside and outside the classroom. Thus, Zuma (2019) agreeably notes that self-experience is aligned to pragmatic curriculum, which is about integration and consideration of students and content needs in a learning space. Accordingly, it can be concluded that self-experience is about combining shared-experience (community needs) with specialised-experience (content needs). This suggests that the aims and objectives of the curriculum being taught are given equal consideration with the outcomes.

5.3 Specialised-Experience and performance curriculum

Specialised-experience is about centralising the needs of the specialisation, whereby teaching and learning is about achieving the needs of the module or content (Khoza, 2015; Khoza et

al., 2021; Mpungose, 2017; Zuma, 2019). Performance curriculum is composed of objectives, whereby the lecturer is an instructor, and formal assessment is prioritised. The objective of an instructional lecturer is teaching by the rules, where students are guided and expected to follow step-by-step prescripts, to attain the curriculum. Hence, it can be said that performance curriculum focuses on the goals of the curriculum rather than the needs of the student, and the main goal is completing the content (Adams et al., 2022). Assessment is summative, which is used to grade students to establish whether they have understood the content learnt or not. Specialised-experience is guided mostly by time (Octaberlina & Muslimin, 2020), therefore when a particular topic is taught, the module concepts, language and context must be comprehended by students speedily so that they produce specific answers expected by the assessor. Furthermore, the summative assessments have a fixed duration (Makumane, 2021); the implication for this is that students are expected to recall, analyse, synthesise and evaluate knowledge in a limited period. As a result, most students fail when performance curriculum is used.

5.4 Aligning framework with this study

Studies involving shared-experience in relation to the use of Moodle in higher education These studies are more concerned about addressing the needs of the community. The purpose and rational for conducting research are closely related to community needs. The observable patterns such as issues of culture, gender and race are used to classify the publication under the shared-experience subheading. Furthermore, studies in this category are reflecting on the use of social media platforms to influence teaching and learning in situations where the user might be the lecturer or the student.

Studies involving self-experience in relation to the use of Moodle in higher education These studies are more concerned about students' or the lecturers' needs. The observable patterns are about ideology/teaching methods/strategies that are utilised by lecturers to accommodate their needs as well the needs of students. Awareness about proper teaching methods assists students find their identity within the curriculum (Acar & Kayaoglu, 2020). Lecturers also understand their own talents, abilities and limitations and devise strategies on how to deliver the curriculum successfully. Subsequently, ideological-ware is discussed by certain scholars in this category as a requirement for blended learning and an essential resource for successful teaching and learning through online-learning platforms during Covid-19. In essence these studies encourage a balanced curriculum that embraces competence, pragmatic and performance. However, challenges such as poor connectivity, lack of data, and geographical location of students are noted as causes for concern for both students and lecturers as they have potential to restrict blended learning.

Studies involving specialised-experience in relation to the use of Moodle in higher education These studies are more concerned about addressing the needs of the module/content.

The purpose and rational for conducting research are about the needs of the module. Universities are concerned about content and assessment coverage regardless of Covid-19 challenges in higher education. Specialised-experience is guided by time, therefore time lost for teaching and learning during lockdowns is prominent in these studies. Moreover, since specialised-experience is less concerned about the needs of the students, these studies focus more on module content coverage and they only accommodate one aspect of the curriculum. It can be concluded that these publications only address or emphasise the challenges faced by higher education institutions during Covid-19 with regards to curriculum coverage.

6 FINDINGS

Tables 1, 2 and 3 display findings of various global studies exploring the use of digital technology such as Moodle in HEIs that demonstrate shared- (Table 1), self- (Table 2) and specialised-experiences (Table 3).

Table 1: Publications that generated the findings - studies involving shared-experience in relation to the use of Moodle in higher education.

	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Tang et al. (2021)	913 participants Survey using a questionnaire	This study explored several key factors in the research framework related to learning motivation, learning readiness and student's self-efficacy in participating in live online learning during the coronavirus outbreak, considering gender differences. The results revealed that female students have higher motivation and better communication in online learning than males.	The motivation of female students was higher because they are more enthusiastic about using communication and technological resources for learning. Moreover, females prefer to use written communication over male students, or females preferred to use written communication over spoken communication. Despite that, the pandemic may be the reason to push male students to participate more actively in live online learning, thus narrowing the gender differences towards student readiness in motivation and communication.

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Table 1 – *continued from previous page*

	Sample size Data collection method	Findings	Discussion and Conclusion
Sakkir and Dollah (2020)	20 undergraduate students from English Education Department of the 2019/2020 academic year Questionnaire and Interviews	The results show that students still prefer to study on campus directly compared to learning from home with various e-learning media. The results also show that the lecturers are not too familiar with other, more varied learning media. The choice of media used is limited. However, students have a positive perception of learning English based on e-learning media during the Covid-19 pandemic.	The study concludes that there are many types of e-learning media used by lecturers in delivering the materials. Students are less interested in the use of media in the learning process. However, the use of e-learning media in the current learning process is an absolute necessity. Favourite learning media frequently used by lecturers in teaching includes Zoom, WhatsApp and LMS, whereas students prefer to be taught with WhatsApp, Zoom, Google Classroom, LMS, and Quizizz.
Maulana et al. (2021)	4 students from 2 groups of teaching staff Data generated using practicality tests, validity tests, effectiveness tests as well as a questionnaire	The findings demonstrate that the learning media developed for online learning during the Covid-19 pandemic based on student learning outcomes is very effective. E-learning learning media developed was proven to improve student learning outcomes.	The findings show that the teaching staff can use this learning media so that its use is not only limited to computer network management design materials but can also be used for learning. The more people use the learning media, the better the transition to digital technology will be.
Mishra et al. (2020)	78 faculty members and 260 students for survey; 20 students and 20 teachers for interviews Survey and semi-structured interviews	Despite having a variety of digital modes of teaching/learning, almost all the teachers and students were using both WhatsApp/ Telegram and email for educational interactions, submission of assignments, clarification of doubts and conducting class tests. Only 32% of teachers were using Google Classroom and 45% were using Zoom/Cisco WebEx/Google Meet/Skype platforms for taking on-line classes (20% and 15% for students, respectively). 25% of teachers conducted webinars as on-line teaching while 35% of students attended university webinars.	At the very onset of the lockdown, teachers intended to use WhatsApp, email and telephonic conversation for imparting teaching. However, gradually as the lockdown period was extended from time to time, they were found to be inadequate. Teachers were given training to explore other online platforms such as Zoom, Google Meet, Telegram, LinkedIn Learning, Sololearn, Udemy, and many more. Three relevant stakeholders, namely academics, technicians and students, started working in tandem to experience and utilise the transition. Students faced specific problems like connectivity and video issues due to the remoteness of their location.

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	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Pustika (2020)	60 English education study program students. Open-ended and closed-ended questionnaire	The finding of this study is that teachers were aware that defining the objective first is important to make the teaching and learning process meaningful. They believed that the learning process needs to be useful as well as meaningful to their students even though the learning process is held virtually.	The future English teachers should be aware of what they will face by following the rapid development of technology. Both advantages and disadvantages of e-learning that they have experienced might be reflection for them to improve and support their e-learning process later.
Mahalakshmi et al. (2020)	175 students across the world Stratified sampling method, data collected with Google Forms	The findings revealed the contribution of e-learning resources or facilities on the students' performance. The study found that there is a generally positive thought among students about e-learning, there is also a great interest in and increasing use of these e-learning programmes for academic use. However, many of them do not wish for e-learning. They only like virtual learning like face-to-face learning or traditional learning.	The online method of learning is best suited for everyone. Depending on their availability and comfort, many people choose to learn at a convenient time. This enables the learner to access updated content whenever they want it. This study showed that e-learning has become quite popular among the students across the world particularly, the lockdown period due to the Covid-19 pandemic.

Table 2: Publications that generated the findings - studies involving self-experience in relation to the use of Moodle in higher education.

	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Khoza et al. (2021)	Purposefully selected publications Pragmatism, critical discourse analysis, and community of inquiry with natural identity	Findings suggested that, while the UKZN had the professional identity of migration through engaging Moodle, it began the migration using WhatsApp, Facebook, Skype, and Zoom video conferencing technology, promoting societal identity. However, the migration seemed to miss the personal or pragmatic identity as an important ingredient of a digitalised curriculum, which addresses individual personal needs.	While staff and students at UKZN managed to complete the 2020 academic year despite the circumstances of Covid-19, a cause for concern still existed regarding the missing awareness of pragmatic and natural identities, the most important ingredients of an effective digitalised curriculum. The situation conditioned the academics to believe that students learned and achieved high marks when they were drilled to master their module content (professional identity of performance digitalised curriculum). However, academics missed the notion that students learn when they are internally ready to learn (mindset), based on their individual needs and situations, irrespective of being with groups/friends or drilled with their course content. Students learn through connecting relevant personal information that addresses their needs.
Simbolon and Tampubolon (2021)	22 students Questionnaires	Based on the analysis and interpretation of research data, it was found that 40.9% of students were enthusiastic about participating in the learning process using Moodle during the Covid-19 pandemic, while 45.45% felt neutral. Students who feel dissatisfied were 9.09% and 4.54% chose to feel very dissatisfied.	Moodle is part of the LMS and as a result, it assists lecturers and students to continue with teaching and learning beyond the classroom walls through delivery of activities, assignments, electronic journal submissions, and other learning resources. From the findings it is clear that although Moodle is a good resource for teaching and learning, face-to-face teaching and learning is also significant to accommodate all students.

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Table 2 – *continued from previous page*

	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Acar and Kayaoglu (2020)	44 students Questionnaire and semi-structured interviews	Quantitative data revealed that there was statistically significant difference between the experimental group and control group, suggesting that the potential contribution of Moodle to learners' language achievement in blended EFL (English as a foreign language) lessons was positive. In the same vein, the qualitative data affirmed that most of the students were satisfied with using Moodle to support English lessons.	The aim of study was to identify whether using Moodle in English lessons as a blended-learning method makes a significant difference in the success of the students in foreign language education. Moodle proves to be an effective online learning tool supporting blending learning. The findings of this study also provide empirical evidence for integrating blended instruction with Moodle in EFL lessons. This is valuable information to the Ministry of National Education.
Lin and Nguyen (2021)	The participant of this study was the researcher (author 1), an international learner in an Australian university. The analytic and evocative autoethnography methodology was employed	The findings show that while the participant could engage with the curriculum to some extent, there are signs of disconnection, isolation and emotional instability associated with the establishment and development of the e-learning environment.	The study concludes that international students' education outcomes could be compromised, and expectations could be unfulfilled via e-learning. Thus, there is a further need to prepare learners for e-learning environments. Illustrations of these emerging issues could help educators better understand the downside of e-learning and e-practice by identifying various influential elements, including individuals' socioeconomic status, cultural heritage and environmental learning settings.
Turnbull et al. (2021)	The databases used in this review were sourced from different search engines. Narrative review: meaning capturing a wide range of articles and views on a research topic.	Moodle was the main platform for conducting asynchronous learning activities in studies that examined the use of online tools in specific courses and programs. However, Moodle was never used by itself as the only weapon in the teacher's online arsenal and was often supplemented by video conferencing tools such as Zoom.	In an online environment, it would be ideal to take advantage of both forms of communication in course delivery; students appreciated the flexibility and trust that asynchronous course delivery gave them to manage their studies. Blended learning can be viewed as a hybrid environment that combines the benefits of traditional learning spaces while exploiting online technologies that enrich learning content and delivery options.

Table 3: Publications that generated the findings - studies involving specialised-experience in relation to the use of Moodle in higher education.

	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Makumane (2021)	10 participants Reflective activities and LMS focus group discussions	Participants supported the use of Thuto LMS as they claimed that it influenced their content knowledge because it was viewed as promoting 'professionalism and easy access to content posted by lecturers'. Participants advocated for the inclusion of more flexible features on the platform, and to a larger extent, an adaptation of LMSs in order to support technological knowledge for socialisation. Perceptions and social perceptions seem to be influenced by habitual perceptions. That is, individual preferences as impacted by their unique interaction with digital technologies promote pedagogical knowledge, which stems from personalisation experience.	The use of LMS is also expected to promote socialisation, where students would interact with theories and content presented. However, in this article, findings demonstrate that Thuto LMS did not allow participants to socialise with the content as it did not permit flexible communication between students and lecturers and among students themselves. The findings further suggest that participants' habitual perceptions were somewhat neglected as Thuto LMS was not aligned to their personal identities in order for them to manage their learning.
Akcil and Bastas (2020)	The sample consisted of 105 people who volunteered to participate in the university. This study was conducted using the correlational survey method which is a qualitative research method.	The findings reveal that the e-learning attitude of students is positive at medium level. Among the reasons may be the unpreparedness for the pandemic. Findings obtained from this study have displayed that students were not prepared for an online learning experience in this pandemic process. Students either fear that they will face many difficulties while working online, or they think that academics will not be able to help enough in the process during the pandemic period.	E-learning attitudes of students are thought to affect their desire for continuing education. High-quality learning experience of students do not only result from the efforts of teachers in e-learning. For faculty students and lecturers, online learning is believed to be more sustainable while instructional activities will become more hybrid provided the challenges experienced during this pandemic are well explored and transformed into opportunities. Lecturers and university managers must raise the technology usage capabilities as regards e-learning to the maximum level in the distance education venture of students.

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Table 3 – *continued from previous page*

	Sample size **Data collection method**	**Findings**	**Discussion and Conclusion**
Adams et al. (2022)	298 undergraduate and 101 postgraduate students. A cross-sectional quantitative survey method was employed in this study. A questionnaire was developed to gauge students' readiness for e-learning.	The findings showed that undergraduate students were mostly ready (65%) compared to postgraduate students (23%) for e-learning. The findings also showed male students were more engaged in blended learning activities than female students. As for students' ethnicity, Indian students were the most interested in online learning compared to other ethnic students.	The findings revealed that students who had the necessary technology skills and knowledge about technology usage were equipped with necessary technology devices and possessed computer and Internet efficacy for an e-learning mode of instruction. This indicates that those students understood the functions and peripherals of computers and laptops and used office software more often. This explains why the male gender and Indian ethnic group are more ready for e-learning because they are exposed to technological usage on a regular basis.
Egielewa et al. (2022)	1134 Nigerian students of the three types of higher institutions in Nigeria. The study used a quantitative survey method whereby the respondents completed a questionnaire via Google Forms.	The study found that students are not satisfied with virtual learning embarked upon by many higher institutions throughout the country during the Covid-19 lockdown and would not want the online learning to continue after the pandemic due to poor internet infrastructure and lack of electricity.	The study concluded that students of higher education in Nigeria have a low acceptance of online learning technology, preferring instead the traditional classroom setting. The study recommends that universities should engage students more interactively not only through texts but also video (e.g. camera demonstrations), increase their online learning during the pandemic and arrange proper internet connection so as not to lag academically, and spend more time on online learning to get the best possible level of instruction until traditional learning resumes.
Mwale and Chita (2020)	Selected students from two universities as end users of e-learning. Thematic analysis of documents and interviews.	Students' responses were characterised by both reluctance and acceptance of e-learning. The students did not express misgivings about e-learning, except for barriers to accessing it.	The students' responses were driven by the perceived ease on the use of e-learning platforms on the one hand, and the perceived benefits of e-learning on the other. Hence, it is recommended that specific contextual realities of students as end users for the effective implementation of e-learning should be taken into account.

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Table 3 – *continued from previous page*

	Sample size Data collection method	Findings	Discussion and Conclusion
Ajani (2021)	Purposefully selected publications.	The author explores and discusses various studies to establish what is known and unknown The challenges of using Moodle by lecturers differ from developed to developing countries. It is mandatory to use Moodle for curriculum delivery in the era of the Covid-19 pandemic, where physical contacts have been limited for social distancing. This study reaffirms the significance of academics' use of different Moodle platforms to deliver the curriculum in South African universities. Academic activities must continue despite the pandemic, to salvage the academic calendar. Hence, Moodle is an effective approach to deliver the curriculum to students in their different locations.	The study concludes that Moodle as a LMS platform has various challenges that should be addressed by the universities for academics to effectively use the platforms for teaching and learning. This includes, planning, self-development of academics and technological infrastructure development.
Terenko and Ogienko (2020)	78 students (Faculty of Philology and Natural Sciences), 12 university staff, and 35 lecturers	Research design which involves quantitative and qualitative methods based on online questionnaires results showed that almost all respondents expressed their concern and uncertainty about the challenge of the Covid-19 pandemic. The teaching staff were concerned about the lack of well-designed web-based curriculum resources. Students noted the difficulties related to visual impairments, unstable internet access and inadequate knowledge on the use of technology.	The transition of teacher training to online mode requires consideration of the fact that the essential feature of the students' future pedagogical activity is constant verbal communication with the participants of the pedagogical process. Teacher training in the Covid-19 pandemic is an international problem. The solution requires the unification of the education community. Transition to online teacher training requires empathy, understanding, and active communication between all participants of the learning process.

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Table 3 – *continued from previous page*

	Sample size Data collection method	Findings	Discussion and Conclusion
Ho et al. (2020)	856 undergraduate students across four campuses located in Hanoi, Can Tho, Ho Chi Minh and Danang A case study of a HEI in Vietnam that used technology in teaching and learning, using a quantitative approach which involved controlled online questionnaires	Findings demonstrate that the interaction between lecturers and students, and among students themselves are important during the period of e-learning since students can seek help from their lecturers and/or classmates whenever they have difficulties in e-learning. The study further highlighted that difficulty with ICT equipment might be a factor that has an impact on attitudes of students towards using technologies in learning.	It is necessary that more emphasis be placed on communicating the benefits of e-learning via a wide variety of channels as well as enhancing the interactivity of e-learning systems. To promote the use of online platforms, the university management should have virtual meetings to connect with students, as well as have specific actions to support students to deal with the academic and psychological issues that could result from learning online.

7 DISCUSSION ON FINDINGS

Studies involving shared-experience in relation to the use of Moodle in higher education

The overall analysis is that despite the many publications around higher education and Covid-19, these studies are limited. One of many possible reasons is the fact that university curriculum is performance based, thus the focus diverged from the community aspect. For example, a study conducted by Tang et al. (2021) revealed that female students were more motivated to communicate and learn online than their male counterparts. However, the wide spread of COVID-19 forced male students to also participate and be accustomed to online-learning because no other means of learning were available to them due to global lockdowns. This demonstrates that issues of gender, culture and race are part of our community and as such they must be given equal consideration in the curriculum.

Correspondingly, another study by Sakkir and Dollah (2020) revealed that teachers and students were using social media platforms such as WhatsApp, Telegram and emails for learning. WhatsApp and Telegram are platforms for socialisation. WhatsApp was designed and introduced as a social platform for smartphones and other users (Prat et al., 2020). It was not designed for education but is used by some universities to communicate formal education (Zuma, 2019). In a similar manner, Telegram has been one of the largest social media platforms in Russia (Adedoyin & Soykan, 2020) but has also been used by students and lecturers for academic communication. This validates that any platform can be integrated to communicate learning. Therefore, it is of essence to embrace those students who learn easier through social platforms, since they learn from each other and by the opinion of others.

Studies involving self-experience in relation to the use of Moodle in higher education Studies of this nature have been published more in comparison to those of shared-experience however, the majority of them are about blended learning. Blended learning is the inclusion of technology into the lesson to continue with learning beyond challenges of no face-to-face contact with students as a result of Covid-19. The selected studies have discussed and embraced all three categories of experiences identified with deeper understanding of ideological-ware resources. For example, Khoza et al. (2021) reveals that UKZN had specialised experience which means that the university is grounded on performance curriculum. However, migration was through social media platforms such as WhatsApp, Skype, Facebook and Zoom video conferencing technology, which are promoting shared-experience (competence curriculum). It can be said that this university used the pragmatic curriculum in its migration because the identity of students and lecturers was at the centre of teaching and learning (Khoza, 2018). Most students and lecturers use social media on a daily basis, hence the university identified this and filled the curriculum in that space.

Studies involving specialised-experience in relation to the use of Moodle in higher education Specialised-experience is dominating on the publications around higher education and Covid-19. Some of the possible reasons for this is the fact that most universities across the globe are grounded on performance curriculum, whereby specialisation is given more priority than shared and self-experiences (competence and pragmatic curriculum). The majority of universities have gone to the extent of supporting students with laptops and data in order to continue with teaching and learning and finish the academic calendar in spite of the countless lockdowns. The support by universities to students is meant to push the content.

In addition, a study conducted by Makumane (2021) revealed that students viewed LMSs as promoting professional identity (performance curriculum) as they get easy access to content uploaded by lecturers. However, students wanted inclusion of more flexible features on the platform for socialisation purpose as the platform did not allow them to socialise (exclusion of competence curriculum). Hence, in that way, the curriculum was not accommodating to their self-experience/ identities to be part of the curriculum (Khoza, 2018). This suggests that lecturers should understand the platform that is used for teaching, and also understand the needs of the students. They should also utilise the appropriate ideology, teaching methods and theories to teaching students, so that the needs of the content, students and lecturer are combined to produce a balanced curriculum.

8 CONCLUSION

This study revealed that there were many publications in the period of Covid-19 that were concerned about performance curriculum/ specialised-experience. There are numerous reasons for this. One of them was the crisis of global lockdowns that forced higher education institutions to cease face-to-face teaching and learning and resort to online learning. Hence,

the focus was on how higher education institutions were going to finish the academic calendar and achieve full content coverage. Moreover, the nature of higher education institutions is competitive (Nicol & MacFarlane-Dick, 2007), which results in the emphasis being put on content coverage to be able to compete with global standards. Consequently, LMSs such as Moodle are used to implement the content-driven curriculum. Therefore, since scholars are a product of such institutions, most of their focus is inevitably on specialised curriculum.

On the other hand, there are limited studies on competence curriculum/ shared-experience in the context of Moodle during Covid-19. However, these studies illustrated that since higher education institutions are part of the community, issues of gender, culture and race and socialisation, must be given equal consideration in the curriculum. Therefore, these studies even recommend that Moodle needs to infuse an aspect of socialisation to be user-friendly to students. Furthermore, there are some studies that embraced the pragmatic curriculum/ self-experience as an effective perspective for effective teaching and learning. These studies demonstrated that when students' and lecturers' needs, ideas, opinions, talents and unique identities are acknowledged and infused in designing the curriculum, the process of teaching and learning becomes successful.

Even though there were limited studies about ideological-ware during the period of Covid-19, they emphasised the essence of ideological-ware in blended learning. For Moodle to be successfully utilised, lecturers need to have teaching strategies and creative ways when using hard-ware and soft-ware for teaching. This involves consideration of the students when thinking about ideas and teaching theories that will be fit for each topic and the resources available. Unfortunately, studies that emphasise the essence of ideological-ware appear to be lacking, yet it is one of the most essential resources for teaching and learning even in critical times and conditions such as during pandemics. Since the future is inevitable, it would seem both prudent and judicious to consider further exploring the different ideological-ware resources that higher education institutions have found to be successful. The sharing of such knowledge will not only assist lecturers and students in facilitating teaching and learning, but it will also guide higher education institutions on the type of training they ought to give both students and lecturers on utilising Moodle.

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Research Article

English first additional language learning and teaching with digital resources

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ABSTRACT
This paper investigates the learning and teaching of English as a first additional Language (EFAL) using digital resources. It was a qualitative study conducted in a Grade 10 township classroom in the Western Cape, South Africa. Data were collected through observation of a traditional classroom, a computer laboratory and a media room. In addition, using semi-structured interviews, an EFAL teacher, the head of department for languages and the school principal, were interviewed. The research aimed to understand whether the pedagogical digital literacy practices and the use of digital resources enhance the learning of EFAL. In South Africa, English is the language of learning and teaching (LoLT) for the majority of learners that are non-English speakers. Through the lens of computer assisted language learning (CALL) theory and Technological Pedagogical Content Knowledge (TPACK), this article argues that the integration of technology helps teachers to deliver the EFAL content in a flexible and enhanced way. The findings reveal that teachers who teach in impoverished backgrounds and in other languages need to be equipped with digital literacy skills. These skills will address the challenges of literacy currently faced by the country. In conclusion, the amalgamation of an e-education policy with the Language in Education Policy (LiEP) and the Curriculum Assessment Policy Statement (CAPS) for the implementation of language digital teaching practices in basic and higher education, should be explored.

Keywords: digital resources, English first additional language, computer assisted language learning, technological pedagogical content knowledge, learning and teaching

Categories: • *Applied Computing* ∼ *Education, e-Learning*

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1 INTRODUCTION

The history of English learning in South Africa started after the Union Convention of 1909 where a decision was taken that English was to be used as the medium of instruction, currently known as a Language of Learning and Teaching (LoLT). These decisions made by British government for political and economic reasons had implications for African education (Ellis, 1997). In the modern 21st century, English is a global language (Desai, 2016, p. 343) and still remains the LoLT in many African classrooms. Learners find themselves struggling to

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understand English content-based subjects and are unable to explain simple problems in English (Deumert et al., 2005), resulting in a linguistic mismatch between home and school (Desai, 2016, p. 344). There is also a mismatch between learners who seem to be technologically advanced, compared to their teachers, who are highly esteemed language practitioners. As technologically advanced as they are, learners are still challenged in expressing their views, either in written or spoken formal English. They are rather comfortable in expressing their views in a digital language where formal English language acquisition is minimal. Therefore, a learner who does English as a first additional language (EFAL) remains linguistically disadvantaged during the school years and beyond, amidst the available technologies.

The above-mentioned linguistic histories hinder the success of many learners in South Africa. Information and communication technologies (ICTs) have benefits for learning such as the use of online and offline integrated learning, quality education and even future business opportunities. There are numerous studies that have addressed the current challenge of English language learning at global, regional and national levels. Desai (2016, p. 343) argues that in South Africa, the learning and acquisition of English requires different approaches, depending on the learners' contexts.

In this research study, the teaching practices of the participant teacher were informed by the work of researchers such as Harris et al. (2009). They advocate that technology integration informs pedagogical practices and enhances the learning and teaching process. They acknowledge that the use of technology in the classroom continues to grow and recognise it as a new methodology that also promotes lifelong learning. Therefore, the focus in this study is on the dynamic ways in which learners learn EFAL, and where teachers bring in their invaluable language teaching skills. Language teaching requires high levels of innovation, creativity, collaboration and scaffolding. In this process, learners are expected to participate actively and engage in the learning process. However, it is not clear if language teachers are making progress in applying digital literacy strategies and competencies, because they are used to traditional ways of teaching (Guðmundsdóttir et al., 2014; Whyte, 2011).

There are overarching reasons relating to why learners are not able to access higher education in South Africa. In a study conducted by Ndokwana (2017) in four secondary schools in the Eastern Cape province, it appeared that, among the other reasons that lead to poor performance in matric results, are the barriers to LoLT as stated earlier on by MacKay (2014) and Sibanda (2014). Ndokwana (2017) goes further to state that isiXhosa speaking EFAL learners misinterpreted grade 12 questions for content subjects like mathematics, accounting and physical science, leading to poor performance in the overall results (Makgato & Mji, 2006; Ndokwana, 2017). South Africa continues to perform the lowest on international benchmark tests, not only in the Progress in Reading Literacy Study (PIRLS) (Howie et al., 2007; Mullis & Martin, 2021), but also in science, technology, engineering and math (STEM) subjects (Ndokwana, 2017, p. 2).

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2 PROBLEM STATEMENT

The above concerns were a motivation for the author to explore how language practitioners address the challenge of second language learning with technology integration. Computer assisted language learning (CALL) researchers such as Lawrence (2010), Peterson (2009), and Ndokwana (2017) address the use of CALL to enhance language learning and teaching from different perspectives. They say ICT integration is a new opportunity and a technology revolution in the language pedagogical domain (Derakhshan et al., 2015). It enables language education practitioners to rethink and restructure the learning and teaching practices without compromising the quality of EFAL teaching and learning (Ghasemi & Hashemi, 2011, p. 3098). However, it is not clear if in South Africa, the integration of ICT in language learning and teaching is being prioritised the way it is in mathematics and science subjects. The fact that the same content subjects that are prioritised also make use of a language seems to be ignored. Therefore, this paper reports on the investigation into the learning and teaching of EFAL using digital resources.

The central question addressed in this study is: How do EFAL teachers integrate technology to enhance language learning in their teaching practices?

The following section provides the theoretical framework that explains the key concepts that pertain to ICT integration for the teaching and learning of EFAL. The discussion highlights the connection between the language teachers' general technological knowledge, teachers' use of digital pedagogical strategies and the relevance of applying these strategies to EFAL content knowledge. The discussion of the research methodology that follows will lead the article to the findings that relate to the research question.

3 COMPUTER ASSISTED LANGUAGE LEARNING

Computer assisted language learning (CALL) provides new learning environments by exploring diverse ICT tools such as advanced games and simulations for the acquisition of language skills in the target language and for meaning-making (Peterson, 2009, p. 73). These environments require teachers to enable EFAL learners to negotiate meaning in order to comprehend and be able to respond to questions effectively. In the EFAL class, social interaction and the negotiation of meaning can take place if the teacher follows teaching strategies that involve learners' tasks which are communicative in order for learners to gain communicative competencies (Chapelle, 2001; Peterson, 2009; Pica, 1994). Others have argued that communicative pedagogies promote learner-centredness, which results in learners being less anxious, becoming confident and developing independent thinking skills in language learning (Ford & Botha, 2010; Shandu, 2011; Tarling & Ng'ambi, 2016; Warschauer et al., 1996). Similarly, these contemporary pedagogies for language learning and teaching could be developed from digital stories (Shandu-Omukunyi, 2022, p. 276) to 3D virtual and augmented learning in any language besides English.

In addition, some CALL researchers (Chapelle, 2001; Lawrence, 2010; Meurant, 2011;

Whyte, 2011) believe that educational technology was advanced for the purpose of developing language skills. Computer technology is used across learning areas to design (van den Berghe et al., 2018; Warschauer et al., 2004) valid ways of evaluating its effectiveness (Ou-Yang & Wu, 2016) as a multimodality approach. On the other hand, technological pedagogy, as described by some researchers (Laurillard, 2013; Webb, 2002; Whyte, 2011) can contribute to areas of language learning and development. For example, second language teaching and learning of grammar (van den Berghe et al., 2018; Whyte, 2011) applies to different genres such as comprehension text, language use and transactional writing, as well as literature. The development of writing skills, as explained by Englert et al. (2005) and Bano and Hameed (2007), would be meaningful if integrated with educational technology. In other words, writing skills cannot be developed if there is still a gap in the development of listening, speaking and reading skills. Therefore, there is a need to pay attention to educational technologies so that EFAL teachers can effectively promote learning and language acquisition efficiently (Ellis, 1997; Laurillard, 2013) using ICT integration.

4 TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

This article is guided by the Technological Pedagogical Content Knowledge (TPACK) framework, developed by Harris et al. (2009) and Mishra and Koehler (2006), which advocates for technology-integrated learning environments that are embedded with content knowledge. TPACK explains the connection in relation to a teacher's general understanding of technological knowledge, their understanding of content as well as their pedagogical practices (Srisawasdi, 2014). The use of the TPACK framework in this article is in line with work by Moll et al. (2022, p. 58) at Wits University where they have sought to understand how teachers recognise the pedagogical affordances of ICT integration, and how they select the digital technologies that would enhance their teaching practices with new methods of communication.

The TPACK model is an interplay of three components, as illustrated in Figure 1, emphasising that the integration of technology with pedagogy is a complex concept. Olofson et al. (2016) interpret TPACK as being relevant to radical constructivism of the 21st century and embracing different types of knowledge construction.

The TPACK model begins with the importance of the teacher's professional identity in relation to language teaching knowledge and the subject matter (content knowledge). Secondly, the teacher should identify the best technological teaching tool that will facilitate the language lesson, thus adding value to the learning and teaching process (technological knowledge). Finally, the selected technological teaching tool will inform the teacher of the transformed pedagogical practice that they should embark on in delivering the lesson. By applying the TPACK model during a language lesson, the teacher facilitates the learning process, whilst the learner learns by participating actively in language acquisition and meaning-making.

Dlamini et al. (2019, p. 198) argue that TPACK guides how EFAL pedagogy, content and technology should be incorporated by a teacher to create an ICT-enhanced and integrated language lesson. However, other TPACK researchers such as Olofson et al. (2016) argue that

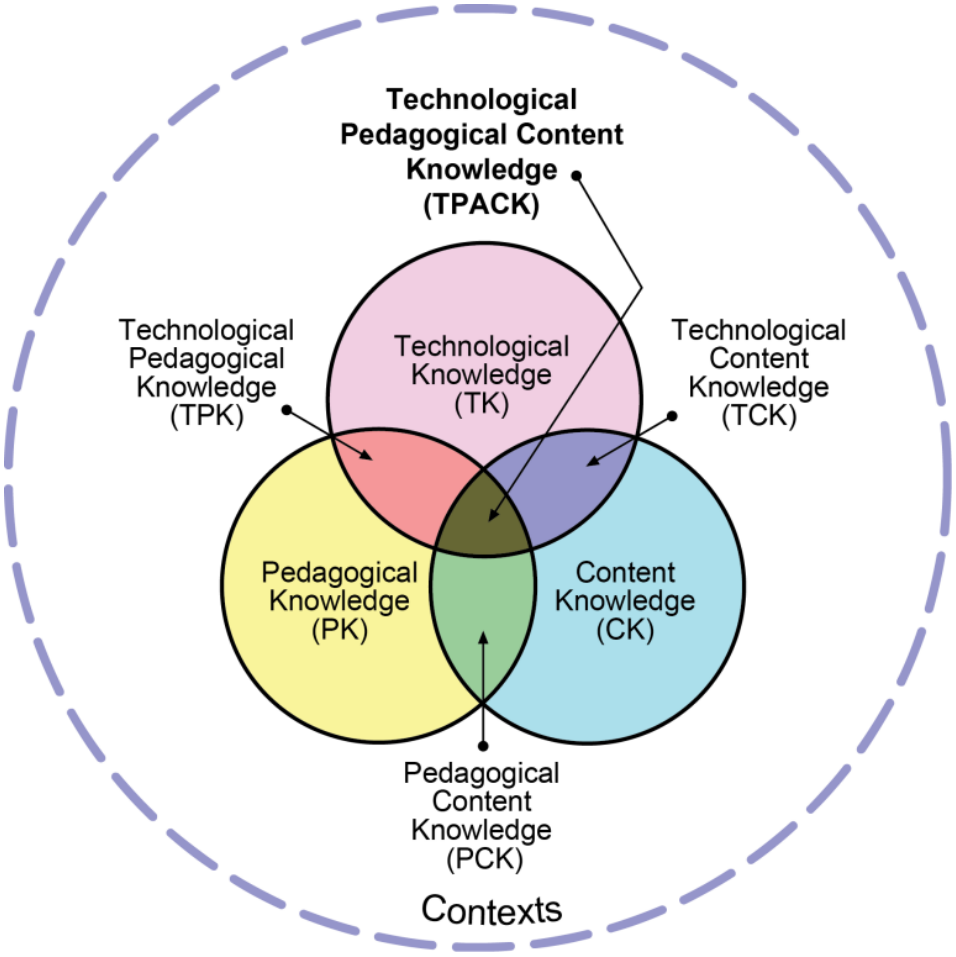

Figure 1: TPACK Convergence[a]

[a]Image reproduced by permission of the publisher, ©2012 by http://tpack.org

TPACK has a fixed way of classifying knowledge. Due to this limitation, they propose a TPACKing concept where TPACK is used as a point of departure in analyzing language teachers' knowledge construction practices (Olofson et al., 2016, p. 188). Whilst Olofson et al. (2016) are concerned with the limitations of TPACK, Koh and Chai (2016) highlight the importance of teaching using collaborative talk during an ICT-enhanced lesson plan design. They refer to their approach as design talk to encourage a learner-centred approach to language curriculum. In a study they conducted with 27 primary school teachers from Singapore, they reiterate that TPACK made the ICT-enhanced lesson design possible (Koh & Chai, 2016, p. 244).

The TPACK framework is also supported by the Substitution-Augmentation-Modification-Redefinition (SAMR) model (Dlamini et al., 2019, p. 27). The first two phases of substitution and augmentation focus mainly on the enhancement of teaching and learning through the use of technology. For example, a teacher may use a Power Point presentation as a substitute for

the chalkboard. The teacher may augment the use of Power Point by giving learners or students a project to create their own presentation from scratch. The second two phases of modification and redefinition focus on the transformation of traditional approaches into ICT integration approaches to learning and teaching (Dlamini et al., 2019, p. 27). For example, learners or students at this stage are able to modify the project, and the integration of technology allows them to construct their own meaning of the project. Therefore, this model enables a learner-centred approach to learning and teaching.

In addition, the conversational framework of Laurillard (2013) supports the concept of TPACKing by Olofson et al. (2016) by proposing the redefining of language learning and teaching practices with ICT integration. The TPACKing concept is supported by language learning theories that promote language acquisition through the learner's constructionist and constructivist approach to learning as opposed to the instructionist approach to language teaching. In a language classroom context, the evidence is seen in relation to learning through acquisition, learning through enquiry, learning through discussion and learning through collaboration etc. However, TPACK researchers in South Africa such as Tarling and Ng'ambi (2016) mention that the teacher's value in their learner-centred approach to learning and teaching is not influenced by the socio-economic status of the school. They refer to affluent, well-resourced schools of the 21st century where teachers continue to teach learners in a traditional way of teacher-centredness. As supporters of TPACK, they argue that the traditional transmission-based pedagogy compromises the ICT progressive transformation of learner-centredness, interactive and enquiry-based language learning (Tarling & Ng'ambi, 2016).

This study explored what is meant by TPACK and CALL in order to uncover and understand how teachers make use of digital resources to enhance EFAL learning in a Grade 10 township classroom. The study also explored the process of EFAL meaning-making through the teachers' pedagogical strategies with lessons that were conducted with and without ICTs. I did this exploration whilst I was mindful of the learners' social and cultural contexts (Ghasemi & Hashemi, 2011; Peterson, 2009) in EFAL learning.

5 RESEARCH METHODOLOGY

This study employed a qualitative research approach and design. Data collection comprised observation in a traditional classroom, computer laboratory and media room. Semi-structured interviews were conducted with an EFAL teacher, the head of department (HOD) for languages and the school principal. The diversity of data collection aimed at applying triangulation as a method of data collection that ensures reliability and credibility (Baxter & Jack, 2008, p. 554).

5.1 Research Site

The research site is one of the schools that were built in the townships as a result of the back to school campaign conducted by Nelson Mandela after the 1994 elections in South Africa. It starts from grade 8 going up to grade 12 and is referred to as a low socio-economic status

school, namely quintile one. Learners walk to school, and are in a feeding scheme programme because the majority of parents are unemployed. The school had a total number of 1,378 learners enrolled during the time of data collection. There were 33 teaching classrooms, 2 computer laboratories that had 30 computers, all in working condition, and a data projector in each laboratory. It also had one biology laboratory, one physical science laboratory and a library with a TV or media room. The total number of grade 10 learners was 357 with approximately 60 learners in each of the six grade 10 classrooms. All of the learners in the school took EFAL as a subject and were taught all other subjects in English as a LoLT.

5.2 SAMPLING AND PARTICIPANTS

The study employed purposeful sampling which involved the EFAL teacher, the HOD for languages and the school principal. The language policy of the school comprises two languages namely, isiXhosa home language and EFAL. Additionally, there are learners that come from the neighbouring African countries and they have learned isiXhosa which should be an additional language in the form of home language. This is the same with those families in that community that have opted to take their children to English home language schools.

5.3 ETHICAL CONSIDERATIONS

The research was conducted in accordance with the research ethics regarding participants' confidentiality, anonymity, respect and voluntary participation (Baxter & Jack, 2008). Ethical clearance was obtained from one of the institutions of higher education where the research was registered. Follow-up permission to conduct research was sought from the Western Cape Education Department (WCED).

5.4 METHOD

The grade 10 EFAL teacher was observed with the learners during a lesson that took place in a traditional classroom, modern computer laboratory and the media room. These observations happened over a period of five weeks.

The main aim was to understand the teacher's digital practices to enhance the learning and teaching of EFAL to isiXhosa home language learners. The observation targeted English language lessons and sought to investigate how the language learning skills of reading and writing are enhanced through teaching with digital resources. In other words, the investigation sought to determine the differences between teaching with modern technologies as opposed to traditional teaching strategies.

5.4.1 Language teaching in the computer laboratory

The first lesson that was observed was in the computer laboratory. Out of the two computer laboratories in the school, one was available for the EFAL teacher and her learners. The two

computer laboratories were mostly used by grade 12 teachers who teach mathematics and physics. However, the grade 10 EFAL teacher was the only one who had made a request from the school's management team (SMT) to use it for language teaching and learning. The teaching resources that the teacher used was a grade 10 EFAL textbook, and teaching digital resources which included computers, a data projector and the interactive whiteboard.

The teacher had planned to teach the Advertising for Language in Action component of EFAL in the Further Education and Training (FET) phase, which starts from grades 10–12. Unfortunately, the computers were not working but the teacher was innovative in playing the video clip she had downloaded earlier on from her memory stick. The audio-visual material from the YouTube video clip was played using a projector and the whiteboard in the computer laboratory. In this lesson, learners were able to compare the differences between the MTN and Vodacom products by exploring their advertising strategies. The multimedia material was used in this lesson to complement and contextualise the content from the EFAL textbook, were digital images from a video clip of the 2010 FIFA World Cup in South Africa as illustrated in Figure 2 (YouTube pictures obtained from the participant teacher).

Figure 2: Mobile network advertising

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5.4.2 Language teaching with television

The media room was located inside the school library; it had bookshelves with books and magazines and newspapers. Tables and chairs were arranged in a way so as to accommodate learners' group work. The space in the room was not enough to accommodate 60 learners. The teaching resources included the EFAL grade 10 textbook, television, DVD player and a computer used by the school librarian. The lesson focused on the use of direct and indirect speech in the 'Language Use' component of the curriculum. The English period coincided with the time of a repeat of a popular South African soap opera known as Generations.

The aim of the lesson was to teach learners the difference between what someone says and when it is being reported on later without changing the meaning. The teacher started by using the traditional teaching method of telling learners about the principles of direct and indirect speech, and the tenses it is used for as a component use of grammar in the English language. The teacher's emphasis was on the change of tense when the sentence changes from direct to indirect speech. After watching a certain part of the soap opera on the television, learners were able to demonstrate what the teacher had taught them independently.

5.4.3 Language teaching in the traditional classroom

The traditional classroom is where the teachers and learners meet every day for learning and teaching. It only had learners' desks, a teacher's table and chair and the chalkboard. There were no visual pictures, teaching aids or language learning material on the walls to enhance the development of reading and writing skills. This lesson focused on transactional writing which is also one of the sections in the FET phase in languages. The lesson was about how to write a formal and an informal invitation. There were no digital teaching resources in this class. Therefore, learners depended on the notes that the teacher wrote on the chalkboard. The main outcome of the lesson was to teach learners how to write for different purposes. Learners were given worksheets with a formal and an informal invitation. They were supposed to work in pairs to read both letters and identify the difference between the two letters.

Semi-structured interviews were used following the interview protocol in order to probe for further information about the use of digital resources to enhance the learning and teaching of EFAL. The interview with the EFAL teacher was conducted to probe for information about differentiation in using both traditional and modern pedagogical strategies to teach language learning and acquisition. The school principal and the HOD were interviewed in order to understand their beliefs about technology integration into language learning and teaching from the perspective of the school's management team. The semi-structured interviews were recorded with the permission from the participants, so that they could be transcribed and coded for the purpose of data analysis.

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6 RESEARCH FINDINGS

This section presents the findings from the school principal, HOD for languages and the EFAL teacher. The categories in which they are presented relate to the teacher's use of traditional and modern teaching strategies for EFAL teaching. These categories relate to the teacher's digital pedagogical strategies that were employed by the EFAL teacher in the teaching of the three lessons in a grade 10 classroom. The findings also highlight the limitations and differences that were observed between digitally enhanced and traditional EFAL learning and teaching. The first category relates to interactive and enquiry-based pedagogical strategies that were used by the teacher to teach EFAL. The second category highlights the pedagogic strategy employed by the teacher within the socio-culturally embedded learning environment with the use of computers and devices such as a television set for EFAL learning and teaching. The last category highlights the gaps found in the non-enhanced EFAL learning and teaching environment.

The findings indicate that there were more digital and pedagogical benefits for EFAL learning and teaching compared to traditional benefits. For example, both the observation and interview data showed that the teacher was able to be innovative in her ICT-enhanced teaching, irrespective of the challenges and disappointments that come with computer technology. However, in a traditional lesson, the teacher ran out of ideas, because even though learners were given the worksheets, they could not relate to the language and could not make meaning from the two letters of invitation. Details regarding the observation and interviews are provided in the next section.

The teacher used different teaching strategies in each lesson. Learners seemed to be enthusiastic whenever lessons took place in an ICT environment. The learners' participation was not active when lessons were not supported by technology. ICT integration encourages a learner-centred approach which is associated with more learner involvement and active learning. Three lessons were observed in total in different venues at the school. Out of the three observed lessons, the teacher used digital resources for lessons in the media room and in the computer laboratory in order to enhance learning and teaching of EFAL.

6.1 Computer interactive and enquiry-based language learning

The findings show that the EFAL teacher was intrinsically motivated to integrate ICT into her teaching practices. Dlamini et al. (2019) refer to intrinsic motivation as the process that occurs when teachers value ICT-integration, and make use of it effectively, whilst an extrinsically motivated teacher uses ICT for job promotion and other related administrative work reasons. As there was limited access to the computer laboratory, the teacher reported that she would sometimes use her own laptop for her lessons as she could not get access to the computer laboratory. The EFAL teacher is an example of an intrinsically motivated teacher. Teachers' motivation to enhance language learning and teaching is supported by the TPACK concept which promotes constructivism (Olofson et al., 2016; Whyte, 2011).

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For example, when the learners were asked if they knew anyone who used MTN or Vodacom mobile phones and why they chose those brands, they were able to interact with the teacher and relate to her question. Though learners did not initially comprehend that advertising is about competition, they were able to construct the meaning from their prior knowledge of Ayoba and Yebo Gogo as shown in the multimedia collage in Figure 2.

During the teacher interview, the EFAL teacher was asked to mention any ICT integration strength she thinks could be a requirement for language learning and teaching. In her response, she mentioned that the integration of technology is important to her teaching practices because learners can visualise what they are being taught. Below are her words during the interview:

> *It is good, learners see things visually even if they have not seen something before they understand better when they see it, and they have more fun which makes them to be more enthusiastic towards learning the English language with ICT. The strength is on the visual and hearing aspect of it; learners like things that are technical in this modern world, and another problem is the lack of resources it is a disadvantage for English L2 especially in "previously disadvantaged" schools.* [Interview with grade 10 English teacher]

The principal's view of ICT integration into English language teaching was that it helps learners to improve in English as it is not their mother tongue. In addition, his main concern was that if the learners' English language acquisition does not improve, it will affect all the subjects that are taught in English as a LoLT.

The three interview respondents had different opinions about the integration of ICT into language learning and teaching. Whilst they all saw the value in the use of digital resources, their interest seemed to be diverse. The EFAL teacher realised that ICT integration into language teaching goes beyond reading and writing as it had been the initial plan for her lessons. She mentioned the development of listening and speaking skills as being the basic skills in the learning of additional languages.

6.2 Socio-cultural language learning

The findings show that learners were very attentive and showed interest when the teacher used ICT. The lesson in the media room enabled learners to understand the transition from direct speech to indirect speech. The learning process here was more learner-centered than teacher-centered as learners could make meaning of what they had learned without the teacher's interference (Tarling & Ng'ambi, 2016; van den Berghe et al., 2018).

When the teacher was asked about the use of ICT for assessment, she was of the view that learners should be assessed through questioning. The teacher's view seemed to suggest that traditional teaching will always be a matter of concern, even if lessons were integrated with technology. Below was her response:

> *One would have to use the old school method of teaching and compare with the computer technology, it can be picked up in the way of questioning them which will determine the way*

they respond to questions, I think that would be a standard way of assessing if there is any improvement with the use of technology . [Interview with grade 10 English teacher]

The teacher's response to the learners' assessment after a lesson that integrated ICT is suggestive of the fact that the scope of exploring the socio-cultural approach to language learning and teaching is wide (Nguyen & Williams, 2016; Peterson, 2009).

Both the school principal and the HOD expressed their concern about improving the grade 12 results and the training of teachers. The HOD mentioned that she personally trained teachers whilst the principal mentioned that teachers require training in computer literacy. Below is the principal's response:

Most teachers must be computer literate because in the beginning of the year the school has an in service training whereby it is expected that each teacher has access to computers for marks capturing and have access to templates that are embedded to the hardware of the computer so that they are able to type their own question papers in specific standard for standardised quality of work. In that way teachers are exposed to computer use.

[Interview with the school principal]

The principal and the HOD responses could be linked to the fact that they represent the school's management team and the WCED, whilst the EFAL teacher's focus is on the content and the development of language skills. The principal's awareness of the ICT gap between mother tongue and English as LoLT, requires further interrogation.

6.3 Implications for EFAL learning

In an EFAL classroom, learners' language skills should develop through listening, speaking, reading and writing. When the teacher talks more than the learners in a lesson, this forces learners to be passive and they consequently do not use the language to communicate with each other. Thus, if they are not given a chance to develop these skills with TPACK, their language learning might be impoverished. Learners do not read or write with comprehension when they are not exposed to interactive learning (Guðmundsdóttir et al., 2014; van den Berghe et al., 2018).

The teachers of the 21st century make use of technology for communication and social interaction purposes such as Facebook, Instagram, Twitter, WhatsApp, video calls, etc. However, it is not clear how language teachers value these technologies as ICT-enhanced tools that could bring meaningful EFAL acquisition. The development and the introduction of artificial intelligence (AI) with computing, virtual and augmented reality, coding and robotics, digital storytelling, and other multimedia tools, are worth exploring for language learning, teaching and assessment. Lack of deeper understanding of the affordances these technologies bring for language learning and teaching, remains a problem. South Africa has a big challenge related to low literacy levels from early childhood development and education through to higher education (Howie et al., 2007). Additionally, the global outbreak of COVID-19 forced more

reliance on the use of technology. This also suggests that the teachers' TPACK skills will afford learners with better ways of learning, particularly those who come from the rural areas and the informal settlements. These factors influence proposals for the exploration of ICT integration through policy implementation, both in the CAPS curriculum (Department of Basic Education, 2019) and the National e-Education Policy of 2004 (Department of Education, 2004).

7 CONCLUSION

The adoption of ICT-integration for teaching and learning poses a challenge both locally, nationally, regionally and globally. In South Africa, EFAL teachers have started to see the value that comes with TPACK. Even though there has been an amendment to the CAPS curriculum document for Further Education and Training (FET), there seems to be no mention of ICT integration. The document specifically focuses on an assessments programme which was due to be implemented in January 2020 (Department of Basic Education, 2019).

The implementation of a new curriculum, the implementation of ICT integration in schools, and teacher in-service training, are means of redressing the structured educational inequalities facing the country. Informed by the TPACK model, the Teaching Change Framework (TCF) of Tarling and Ng'ambi (2016) is not specifically directed to language and literacy teachers and practitioners. However, many language researchers (Desai, 2016; Ellis, 1997; Kerfoot, 2009; Lawrence, 2010; Ou-Yang & Wu, 2016; Shandu, 2011; van den Berghe et al., 2018) support the notion by stating that in language and literacy learning and teaching, the focus should be more on meaning-making, particularly in EFAL in South African classrooms. This article recommends that the Language in Education Policy (LiEP) and e-education and CAPS policy makers should merge and share their expertise for language teachers in both pre-service and in-service training. This is to ensure that they are equipped in understanding the latest digital technologies and form part of global digital citizenship. EFAL teachers will also understand and gain awareness of what is entailed in AI tools such as ChatGPT. Access to the above digital literacy skills prepares language education teachers to enhance and support EFAL learning and teaching, particularly during the times of pandemics, where ICT integration is enabled by online learning.

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