SACJ - Volume 35 Number 2 - December 2023

South African Computer Journal

December 2023 - Volume 35 Number 2

ISSN 1015-7999 (print)
ISSN 2313-7835 (online)

South African Computer Journal

Volume 35 Number 2, December 2023
ISSN 1015-7999 (print) – ISSN 2313-7835 (online)

A publication of the South African Institute of Computer Scientists and Information Technologists
Open Access: https://www.sacj.org.za

South African Computer Journal

NOTES FOR CONTRIBUTORS

The *South African Computer Journal* is an accredited specialist academic journal, publishing research articles, technical reports and communications in English in the Computer Science, Computer Systems and Information Systems domains. Its primary target is research of interest in Africa or published by African researchers, but all quality contributions are considered. All research articles submitted for publication are rigorously refereed by independent peer reviewers. The journal publishes original work that is of international stature. The editorial board comprises local and international scholars of high repute. The journal is published online using the *open access* model, making papers accessible in developing countries where funding to subscribe is scarce.

Submissions

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.

Form of Manuscript

Manuscripts for *review* should be prepared according to the following guidelines, which summarize more detailed instructions on the web site.

SACJ has a double-blind reviewing policy. No author's name or affiliation should appear anywhere. Citing of previous work by the author or authors should be anonymised if appropriate. Acknowledgments and thanks should not be included in the draft for review. If you use Microsoft Word please make sure that your name and affiliation are not saved in the document properties.

- The article should start as follows:
  - the title (as brief as possible)
  - an abstract of less than 200 words
  - an appropriate keyword list
  - a list of ACM Categories (2012 scheme).
- Tables and figures should be numbered, in sequence, titled, and referenced in the text by number.
- *SACJ* uses American Psychological Association 6th edition style in final, published papers, as described here (https://apastyle.apa.org/). Manuscripts for *submission* should use numeric citation, as APA version 6 is difficult to get right. References should be

listed at the end of the text in alphabetic order of the (first) author's surname and cited in the text.

If you use an appropriate BibTeX style, this will work automatically; do not spend a lot of time on reference citation minutiae since the production editor will take care of that sort of detail.

- If a DOI is available for any reference cited, include the DOI in the reference list. The DOI should be a complete URL (ideally clickable), for example: https://doi.org/10.18489/sacj.v34i1.1115 (DOI display guidelines here: http://www.crossref.org/02publishers/doi_display_guidelines.html)
- If a DOI is not available a URL to the original document or the publication containing the document should be provided.

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.

Authors retain the right to republish their work, subject to any republished version including a reference to the *SACJ* version.

Publication Charges

A charge of R6000 will be levied on papers accepted for publication to cover costs of open access publication. Where the author's institution or research budget is unable to meet this charge, it may be waived upon request of the author and at the discretion of the editor-in-chief.

Proofs

Proofs of accepted papers will be sent to the corresponding author to ensure that typesetting is correct, and not for addition of new material or major amendments to the text. Corrected proofs should be returned to the production editor within three days.

Extended Conference Papers

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

- a covering letter accompanying submission should explain what is added to the paper to make it worth publishing as a journal paper
- the paper includes at least 30% new material

- a pointer is provided to the original paper or, if it is not freely available, upload it as supplementary material when submitting the extended paper to *SACJ*
- 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.

South African Computer Journal

Volume 35 Number 2, December 2023
ISSN 1015-7999 (print) – ISSN 2313-7835 (online)

A publication of the South African Institute of Computer Scientists and Information Technologists
Open Access: https://www.sacj.org.za

CONTENTS

continued . . .

South African Computer Journal

CONTENTS (CONTINUED)

KMSA Special Issue

Viewpoints

Editorial: A new era for SACJ

Katherine M. Malan – sacj.editor@gmail.com
Department of Decision Sciences, University of South Africa

SACJ joins Khulisa Journals

The first editions of SACJ (then under the name *Quæstiones Informaticæ*) were printed on paper. In 2010, SACJ took a bold step from the traditional printed journal and published its first online issue as an open-source journal. December 2023 comes with another change, as the first SACJ issue to be published from the platform hosted by Khulisa Journals. With our URL in place (https://www.sacj.org.za/), we trust that the transition will not be too disruptive for our authors, reviewers and readers. In the transition period (as we complete submissions currently under review on the old site and build up the archive of back issues on the new site), the current site, http://sacj.cs.uct.ac.za – kindly hosted by UCT's Department of Computer Science – will stay open, but not for new submissions. We are happy to have a formal association with the Academy of Science of South Africa (ASSAf) via Khulisa Journals, and look forward to fruitful collaboration with our fellow South African scientific publishing community.

Reflecting on the move from printed to digital media is appropriate this month for another reason. Prof. Jan Kroeze, recipient of the SAICSIT Pioneer award in 2022, will be retiring at the end of the month as Professor from the School of Computing, UNISA. As part of his handover, he will be driving a boot-load of printed issues of SACJ to Potchefstroom to add to the collection of the North-West University Library. These are from the personal collections of Prof. Derrick Kourie, Prof. Judith Bishop, Prof. Ruth de Villiers and Prof. Jan Kroeze. We are grateful for this donation to the NWU Library, in so doing ensuring that we have a full collection of the printed issues of our journal safely archived in one place. Thank you also to Mr. Nestus Venter and the Science Library at NWU for hosting the collection.

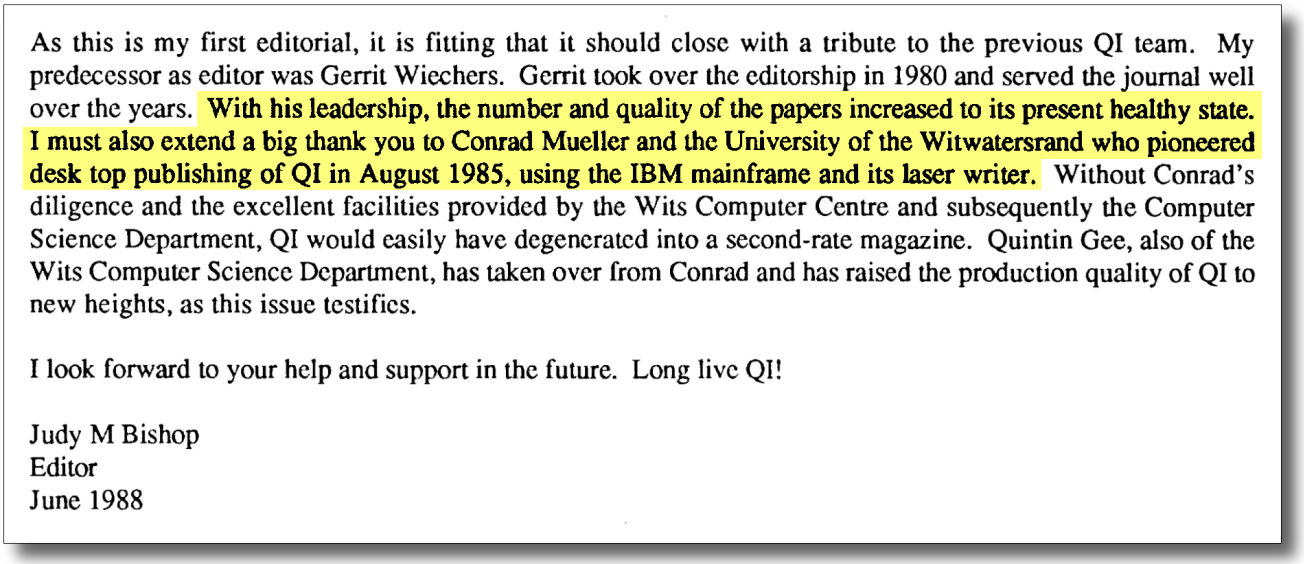
In memory of Conrad Mueller

To start the issue, we honour the life of Conrad Mueller – another point of synchronicity as we reflect on the history of SACJ. After some digging in historical records, I have deduced that

Malan, K.M. (2023). Editorial: A new era for SACJ [Editorial]. *South African Computer Journal* 35(1), vii–ix. https://doi.org/10.18489/sacj.v35i2.17439

SACJ is a publication of the South African Institute of Computer Scientists and Information Technologists.
ISSN 1015-7999 (print) ISSN 2313-7835 (online).

Conrad served our community as the first production editor of SACJ (when it was called *Quæstiones Informaticæ*). An extract from the editorial of Volume 6, Number 1, 1988, in Figure 1 confirms that Conrad preceded Quintin Gee, whom Derrick Kourie erroneously names as the first to be responsible for the "onerous task" of professional typesetting of the journal (Bishop, 1988; Kourie, 2010). The editor at the time of the 1988 issue, Judith Bishop, refers to Conrad as a "pioneer" with his tools being an IBM mainframe and a laser writer.



As this is my first editorial, it is fitting that it should close with a tribute to the previous QI team. My predecessor as editor was Gerrit Wiechers. Gerrit took over the editorship in 1980 and served the journal well over the years. With his leadership, the number and quality of the papers increased to its present healthy state. I must also extend a big thank you to Conrad Mueller and the University of the Witwatersrand who pioneered desk top publishing of QI in August 1985, using the IBM mainframe and its laser writer. Without Conrad's diligence and the excellent facilities provided by the Wits Computer Centre and subsequently the Computer Science Department, QI would easily have degenerated into a second-rate magazine. Quintin Gee, also of the Wits Computer Science Department, has taken over from Conrad and has raised the production quality of QI to new heights, as this issue testifies.

I look forward to your help and support in the future. Long live QI!

Judy M Bishop
Editor
June 1988

Figure 1: Extract from the editorial of Quæstiones Informaticæ, Volume 6, Number 1, 1988.[a]

[a]Bishop (1988)

Research in this issue

We have a wide range of research papers included in this issue, across different topics and from different institutions in South Africa:

- *Spectrum-Aware Transitive On-Demand Routing Protocol for Military Cognitive Radio Ad Hoc Networks* by Phaswana and Velempini, Department of Computer Science, University of Limpopo.
- *The Influence of Change Management Process on Cloud Transitioning* by Miyen and Marnewick, Department of Applied Information Systems, University of Johannesburg.
- *Virtual learner experience (VLX): A new dimension of virtual reality environments for the assessment of knowledge transfer* by Steynberg, van Biljon and Pilkington, School of Computing, University of South Africa.

- *Online Platform Privacy Policies: An Exploration of Users' Perceptions, Attitudes and Behaviours Online* by Mugadza and Mwalemba, Department of Information Systems, University of Cape Town. This paper is part of a special issue of extended papers from the SAICSIT 2022 conference handled by guest editor, Prof. Aurona Gerber. Another two extended papers from SAICSIT 2022 will be published in the next issue of SACJ.
- *Challenges of Implementing Enterprise Resource Planning and the Role of Knowledge Management: Evidence from National Youth Development Agency* by Zuma and Sibindi, Department of Management and Entrepreneurship, University of the Western Cape. This paper was presented at the Knowledge Management South Africa Imbizo 2023, handled by Prof. Hanlie Smuts.

In addition to the peer-reviewed research papers, we also have two Viewpoints from our colleagues in war-torn Ukraine. As in the last issue of SACJ, we are playing a small part in supporting the work of researchers from the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine by disseminating their work.

References

Bishop, J. M. (1988). Editorial. *Quæstiones Informaticæ*, *6*(1), 1. https://uir.unisa.ac.za/bitstream/handle/10500/23824/1988_QI_06_01_De%20Villiers_von_Solms.pdf

Kourie, D. G. (2010). The South African Computer Journal: 1989 to 2010. *Transactions of the Royal Society of South Africa*, *65*(2), 107–111. https://doi.org/10.1080/0035919x.2010.510664.

Obituary – Conrad Mueller

Robert L. Baber[a] – bob@rlbaber.de,
Yinong Chen[b] – yinong.chen@asu.edu,
Scott Hazelhurst[c] – scott.hazelhurst@wits.ac.za,
Philip Machanick[d] – p.machanick@ru.ac.za,
Sarah Rauchas[e] – Sarah.Rauchas@wits.ac.za

[a] Retired
[b] School of Computing and Augmented Intelligence, Arizona State University
[c] School of Electrical & Information Engineering and the Sydney Brenner Institute for Molecular Bioscience, University of the Witwatersrand, Johannesburg
[d] Department of Computer Science, Rhodes University
[e] School of Computer Science and Applied Mathematics, University of the Witwatersrand, Johannesburg

---

Conrad Steven Martin Mueller, a pioneer of computer science at Wits and in South Africa died on 23 November 2023. He was born in Johannesburg in 1949, and matriculated at King Edward VII High School. He completed his BScHons at Wits. After spending a short time in industry, and completing his MSc at RAU (now UJ), he returned to Wits in 1981 in response to a call to help a new division as it was emerging into an independent Department of Computer Science. He spent the next 33 years at Wits, rising through the ranks to associate professor. He served as Chair of the Governing Committee and then Head of School for about 10 years.

Conrad quickly proved himself to be an extremely dedicated teacher in a really tough environment. Wits, as an established research university, considered Computer Science to be an upstart new discipline, particularly as few members of staff had PhDs in the early days. Conrad's great strength was the time and interest that he put into the people around him. As a teacher he is fondly remembered for the one-on-one work that he did with students. In the 1980s and 1990s it was common to find a queue of students outside his office getting help. He would spend hours with students helping them debug their terrible code, and more importantly teaching them and fostering independent thinking.

Baber, R.L., Chen, Y., Hazelhurst, S., Machanick, P., and Rauchas, S. (2023). Obituary – Conrad Mueller [Obituary]. *South African Computer Journal* 35(2), 1–2. https://doi.org/10.18489/sacj.v35i2.17440

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

Conrad mentored young members of staff, advising them on teaching strategies and how to deal with various teaching and administrative problems. He could always be relied on to read drafts of research papers critically and constructively and was happy to listen to research problems and talk through possible solutions even for projects outside of his area of expertise. Conrad was always prepared to take on administrative tasks, large and small, and sheltered the younger members of staff from that work. This nurturing mentorship launched several academics into their own successful careers.

Conrad had to be pretty tough to protect and help build computer science as a discipline. Yet in the end, the new department met with some great successes, particularly students who went on to become industry leaders.

Conrad was an old-fashioned scholar – he read widely and deeply and had an open sense of enquiry. He taught a wide range of computer science courses from first year to honours. He made important contributions to computer science education research. His research passion was computer architecture – he recognised early the limitations of the von Neumann architecture and proposed alternative models and programming styles. He completed his PhD in the late 1980s under Judith Bishop – *Towards removing sequential ordering in programs* – and continued work on this theme for the rest of his life.

Conrad was active in SAICSIT for many years, and published both in *SACJ* and in the annual SAICSIT Conference. For many years he was production editor of *Quaestiones Informaticae*, the predecessor of *SACJ*.

As a son of German and Swiss immigrants who had seen the rise of fascism in Europe, Conrad was brought up to oppose apartheid. He was a member of Mervyn Shear's "Peacekeepers", a group of academics who in the 1980s would put themselves between the police and students in an effort to restrain police violence, and active in the anti-apartheid Union of Democratic University Staff Associations.

After Conrad reached mandatory retirement age, he taught at Tshwane University of Technology and continued to supervise postgraduate students at UNISA. He was also elected to the Wits Executive Committee of Convocation and was one of the Convocation members of the University Council. He gave great service to the university and could be relied upon to take on unglamorous jobs. He showed particular commitment and personal courage during the Fees Must Fall protests.

Conrad was always a great personality and someone who was a good friend as well as a colleague. He was also a pioneer of good coffee. The departmental wine club, Turing Tipplers, held his sense of taste and smell in high regard. He often entertained colleagues at home, and would show immense kindness to new members of staff, putting them up and even schlepping them around town. In cases of personal crises, he was always willing to help. His unusual turns of phrase – Conradisms as his staff irreverently called them – can't be repeated (though they never fell on flat ears). You had to be there to appreciate them.

Conrad's sense of what was right meant that he sometimes would not compromise. He could not resist the temptation to argue or disagree with positions that he thought were wrong. As a result, he could drive his colleagues to distraction and was the bane of generations of Deans and Vice-Chancellors. But his sincerity and passion left Wits and computing in South Africa a better place.

He is survived by his partner Judy Backhouse and sisters Ann-Christine Andersen and Jane Mueller.

https://doi.org/10.18489/sacj.v35i2.17440

SACJ 35(2) December 2023
Research Article

Spectrum-Aware Transitive On-Demand Routing Protocol for Military Cognitive Radio Ad Hoc Networks

Phetho Phaswana, Mthulisi Velempini

University of Limpopo, Department of Computer Science, South Africa

ABSTRACT
The advancement of wireless technology is increasing the demand for scarce spectrum. Cognitive radio ad hoc networks (CRAHNs) were proposed as a solution to spectrum scarcity which is also deployed in combat. However, military cognitive radio ad-hoc networks (MCRAHNs) are subject to destruction and frequent link breakages. The challenge with MCRAHNs routing is the timing-out of packets. This paper proposes the spectrum-aware transitive multi-cast on-demand distance vector (SAT-MAODV), optimised for throughput and delay. The relay nodes are selected based on zonal data and mobility. This is achieved through handshaking and sharing of location data. The nodes are expected to store location data of nodes encountered, which is used in routing and in determining the movement of the node. The mobility of military nodes is organised and structured, which simplifies routing. The SAT-MAODV was evaluated in network simulator 2 and the results show that the scheme is effective. Using SAT-MAODV instead of xWCETT, it reduced routing path and node relay delay by at least 65% and 13% respectively, and increased achievable throughput by 31%. It also improved the delivery ratio by 9% while reducing latency by 27% in comparison with MARSA.

Keywords Spectrum Depletion, Cognitive Radio Ad Hoc Network, Routing Path delay, Throughput

Categories • **Networks** ∼ **Network protocols, Network layer protocols, Routing protocols**

Email
Phetho Phaswana – phethopp@yahoo.com,
Mthulisi Velempini – mvelempini@gmail.com (CORRESPONDING)

Article history
Received: 26 March 2022
Accepted: 23 July 2023
Online: 14 December 2023

1 INTRODUCTION

In intermittent mobile networks, there are no guaranteed routing paths due to the instability of the network. A military cognitive radio ad hoc network (MCRAHN) is a network consisting of nodes such as soldiers with wearable devices, tankers, armoured fighting vehicles, armoury with sensors, and aircraft. If these nodes are destroyed, the routing paths may not be guaranteed. In the process of relaying data packets, the transmission may be interrupted due to the unavailability of relay nodes. This results in delays which may degrade the performance of

Phaswana, P., and Velempini, M. (2023). Spectrum-Aware Transitive On-Demand Routing Protocol for Military Cognitive Radio Ad Hoc Networks . *South African Computer Journal* 35(2), 3–24. https://doi.org/10.18489/sacj.v35i2.17389

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

the network. Some packets are dropped due to prolonged buffering and timeouts. The delays which are incurred in MCRAHNs due to node destruction are spectrum mobility (SM), node relay (NR), and routing path (RP). The destruction of nodes also degrades achievable throughput as the packet drop rate increases exponentially (Tuukkanen, Couturier, Buchin, Braysy et al., 2018).

When designing a routing algorithm for MCRAHNs it is imperative to first address the destruction of nodes and route recovery mechanisms. Several routing algorithms have been proposed to address routing challenges in MCRAHNs. However, most of the algorithms do not address MCRAHNs delays. The reduction of delays and optimisation of the MCRAHNs for throughput and delays improves the efficiency of MCRAHNs. Applications which are intolerant to delay and latency are emerging, which also require high data rates and efficient protocols such as medium access control (MAC) and routing protocols (Ahmad et al., 2019; Akyildiz et al., 2020).

Spectrum mobility is another challenging factor that should be evaluated in MCRAHNs. Spectrum scarcity in MCRAHNs makes packet transmission more challenging. In designing routing algorithms that are optimised for frequent partitioning of the network due to node destruction, the following challenges should also be considered: spectrum access, spectrum and node mobility (Kumar, 2018). Spectrum access in MCRAHNs is different from CRAHNs in the sense that in MCRAHNs it has to be fast, efficient, and robust because packets must be transmitted immediately before any destruction occurs. In cases where destruction has occurred, spectrum access must take place in a partitioned network with missing nodes (Kumar, 2018). Route repair is therefore fundamental in MCRAHNs.

The proposed scheme, the spectrum aware transitive multi-cast on-demand distance vector (SAT-MAODV) seeks to address these MCRAHN challenges. SAT-MAODV integrates multi-cast routing, reactive distance vector routing, spectrum awareness and transitivity into a robust, efficient, and resilient scheme. Addressing the delay, spectrum and node mobility challenges of MCRAHN is significant to the success, stability and connectivity of military networks.

This paper is organised as follows: The related work is presented and analysed in Section 2 while Section 3 describes the proposed scheme and the techniques used. The results of the study are presented and discussed in Section 4. Finally, Section 5 concludes the study.

2 RELATED WORK

One of the most common methods used to mitigate delay in CRAHNs is the loosely coupled cross layered design (LCCLD) (Kumar, 2018). The network layers according to the Open Systems Interconnection (OSI) model are merged and optimised for quality of service (QoS) to form more robust layers which can reduce delay. Kumar (2018) proposed a routing scheme that combines routing with resource allocation for CRAHNs. The scheme routes packets based on the resources of spectrum channels that are supposed to provide sufficient QoS. When routing packets in CRAHNs, depending on the primary user (PU) activities and traffic load and density, the available spectrum resources vary between transmission attempts (Deng et al.,

2018). The variations in QoS are caused by PU activities and the traffic load. More PU activities result in fewer resources to meet the QoS requirements. This means QoS for the secondary user (SU) may not be met.

One other routing method that is frequently used in mobile ad hoc networks is shortest path selection which is based on the Dijkstra algorithm (Towhidlou & Shikh-Bahaei, 2018). It is an efficient way of finding the shortest paths to the destination. Towhidlou and Shikh-Bahaei (2018) proposed a routing protocol called SACRP (spectrum aggregation-based cooperative routing protocol) which is based on aggregation, cooperative routing and shortest path selection. SACRP is efficient in reducing end-to-end delay. For route selection, SACRP uses the shortest path selection method as a first step to discover unutilised routes. It calculates the route distance of every unutilised route. The information about the unutilised routes is compared to the stored route information and the shortest path is then selected.

Routing based on channel conditions is a good method of reducing spectrum mobility delay. Channel conditions must be considered so that transmissions can be successful. SACRP (Towhidlou & Shikh-Bahaei, 2018) included a technique which incorporates features such as channel conditions in routing to reduce spectrum mobility delay in intermittent CRAHNs. It cannot buffer packets until routes are discovered. The buffered packets are dropped when new routes are not discovered soon. The features of SACRP can be integrated with a routing protocol designed for intermittent CRAHNs. The protocol should also be optimised for spectrum mobility delay reduction. Delay minimisation routing can be integrated with spectrum aggregation approaches where spectrum availability data is stored for reference to inform spectrum access decisions.

Spectrum mobility in MCRAHNs makes it more challenging to design efficient routing algorithms. Most routing algorithms fail to address the dynamic nature of spectrum bands and fail to utilise effectively, the available spectrum channels. Ji et al. (2015) proposed a spectrum-aware routing scheme for cognitive radio networks (CRNs) called spectrum-aware semi-structure routing (SSR). SSR is mainly based on the utilisation of the available spectrum. Unfortunately, most routing algorithms are not optimised for the dynamics of spectrum availability in CRNs (Hrabcak et al., 2018). SSR is a joint routing scheme, which combines routing with a power control framework. Power control is often used in wireless sensor networks (WSNs) to prolong the lifespan of a network (Bouallegue et al., 2018). It is also very important to consider it for MCRAHNs since unstable paths can cause nodes to buffer packets for a long time which requires a lot of energy.

Node mobility is another challenge which impacts the designing of routing algorithms in MCRAHNs. The location of nodes in ad hoc networks determines the routing approach. In large networks factors like the transmission range also contribute to this challenge whereby some nodes are outside the transmission range of the sending node. Geo-routing (geographic routing) is focused on dealing with this challenge. In geo-routing, the source node sends packets to the geographic location of the destination node.

Tayel and Rabia (2018) proposed a protocol called the Internet Protocol Spectrum Aware Geographic based routing protocol (IPSAG) for CRNs. The protocol uses geographic location

and spectrum awareness. IPSAG uses predefined knowledge of the spectrum and the geographical location of nodes.

In IPSAG, all the nodes have the required information about the geographic location of all the nodes that are within the specific network. When a node receives a packet, it first checks its buffer for the location of the destination node and then forwards the packet using the greedy forwarding strategy: the next hop must be the closest current node's neighbour to the destination (Anushiya & Suganthi, 2018). IPSAG also checks for the nodes which have common spectral quality before it forwards the packets. If the transmitting node has the option of transmitting to two or more nodes through the greedy forwarding strategy, then the spectral features are evaluated. The node that offers more QoS in terms of spectral quality is chosen.

2.1 Routing for Delay Sensitive Real-Time Critical Applications

MCRAHNs protocols cannot be directly applied to time-critical automation applications due to spectrum mobility, node mobility, and stochastic PU activities. A protocol called Delay-Minimised Routing (DMR) was proposed to address this problem (Sabbah et al., 2018). In designing DMR, a model was developed based on conflict probability. This model is used to detect any forms of routing conflicts in the network when routing paths have the same value (Sabbah et al., 2018). The model helps resolve such conflicts. In this study, a new routing metric called the minimum path delay was also proposed. This metric is used to evaluate the delay that is incurred in routing protocols. By using the conflict probability model, the DMR outperformed related protocols in end-to-end delay, minimum path delay, throughput, and packet loss rate.

In intermittently connected networks, packets are often replicated with the hope of reaching the destination. This routing approach causes unnecessary congestion in the network and at the nodes. Tegou et al. (2018) designed a routing protocol called Ferry Enhanced PRoPHET to address congestion caused by packet replication. Nodes called ferries are used to control the replication of the packets. The ferry nodes move within the network exchanging packet information. The packets that have already been delivered are marked delivered. The rest of the nodes are also informed about the delivered packet. The packets are then deleted when all the nodes have updated their buffers accordingly.

The comparative results show that the epidemic algorithm performs better than Ferry in terms of delivery ratio. Ferry was derived from an algorithm called Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) which uses transitivity to route packets in intermittent networks (Wen et al., 2018).

Most intermittent algorithms flood the network with copies of packets. They replicate the packets until the destination receives the packet. However, Ferry has fewer replicated packets compared to epidemic and PRoPHET algorithms. Ferry enhances PRoPHET however; it lacks spectrum awareness which is ideal for MCRAHNs. We considered the intermittent routing attributes of the Ferry in the design of our proposed scheme.

https://doi.org/10.18489/sacj.v35i2.17389

2.2 Routing Challenges and Delay

The challenge of relaying packets is very eminent in Sleep-Wake Cycling Wireless Sensor Networks (WSN) whereby the paths from source to destination are not guaranteed. Due to the limited energy, the nodes take turns to be active. Relaying packets poses a challenge when nodes sleep when idle. Such a network can be regarded to be intermittent since paths are not guaranteed. The main challenge is designing a routing algorithm which can perform well without incurring a lot of end-to-end delays and node relay delays.

Guo et al. (2018) discussed some of the delay-related algorithms. However, they lack the cognitive features required for opportunistic spectrum access. In our study, we incorporated some features of Sleep-Wake Cycling WSN since they share similarities with intermittent CRAHNs.

Gharajeh (2018) used neighbouring nodes to transmit data packets based on the residual battery energy. The depletion of battery energy results in the node becoming unavailable which partitions the network. This is similar to nodes being destroyed in military networks though, in the military, networks nodes can be destroyed at any given time. Their unavailability is not determined by the depletion of the battery energy. There is therefore a need to consider the sudden destruction of nodes.

Khanmohammadi and Gharajeh (2018) proposed a clustering-based routing protocol designed to extend the lifespan of a sensor network based on energy conservation. The objective of the protocol is similar to the approach by Gharajeh (2018) however, it is not optimised for military networks where the non-availability of nodes is caused mainly by their destruction in combat.

A neural networks-based protocol was proposed by Khanmohammadi and Gharajeh (2017) to prolong the lifespan of the network based on the residual battery, distance, and response time of the next hop. The protocol is novel however, it is not suited for military networks where the unavailability of a node is non-deterministic.

2.3 Military Networks and Multi Casting

A number of schemes were designed for military-related networks (Amanowicz et al., 2012; Bräysy et al., 2017; Onem et al., 2013; Suojanen & Nurmi, 2014; Tang & Watson, 2014) and optimised for end-to-end QoS. However, in military networks, survivability and fault tolerance of the network is fundamental and critical. The deployment of CRAHN in the military is key to the success of intermittent networks (Tuukkanen, Couturier, Buchin, Bräysy et al., 2018). Routing and MAC protocols are reviewed by Lee et al. (2021), while Kaszuba-Chęcińska et al. (2021) proposed a policy-based radio and a sensing method.

According to the literature, the following schemes are promising: multi-cast On-Demand Distance Vector algorithm (MAODV) (Jhajj et al., 2019), Extended Weight Cumulative Expected Transmission Time (xWCETT) (Kola & Velempini, 2018) and Mobility-Assisted Routing algorithm with Spectrum Awareness (MARSA) (Huang et al., 2014). The results show that they are best performing. These schemes were compared to our proposed scheme.

https://doi.org/10.18489/sacj.v35i2.17389

The performance of CRAHNs is degraded by several challenges such as node relay delay, node mobility, and spectrum mobility. These challenges affect mainly routing. When a link node moves out of range, packets which are being transmitted are dropped if alternative paths are not established on time which impacts negatively on the performance of the network. Spectrum mobility has the same effect. When a node is forced to switch from one band to another due to PU activity, it partitions the network leading to packets being dropped. This causes relay nodes to buffer packets for a long time in the event of link breakages while waiting for the establishment of new alternative routes. Furthermore, the depletion of batteries of relay nodes has the same effect. In MCRAHNs, similar challenges are also caused by the destruction of nodes in combat.

The schemes which were designed to address these challenges have partially solved these challenges. In some instances, residual battery power is not considered in the selection of routing paths. Spectrum mobility may be considered in spectrum access decisions and for routing purposes. Furthermore, the uniqueness of MCRAHNs and the destruction of nodes in combat is not considered for routing purposes in most schemes.

3 OUR PROPOSED MODEL

SAT-MAODV uses a multi-cast technique called the Informed Centralised Multi-cast (ICM) technique where a specific zone of the network is selected for zonal routing based on the data stored by the MCRAHN nodes. The availability of a route also determines the selection of a given zone. If the zone does not have a link to the destination due to route breakages and network partition, the selected zone should have a higher probability of relaying packets to the destination. This is achieved through the implementation of the Node Roaming Area (NRA) technique. Each node in the MCRAHN has a specific zone that it is most likely to roam in given that military networks are structured and strategically positioned. In addition, nodes have a buffer to store the locations of encounters. The duration of data storage is dynamic given the mobility of nodes. When nodes exchange location data, the NRA computes the probability of given nodes moving into a given zone in the event of link breakages. We refer to the zone that a node frequents as the NRA zone.

SAT-MAODV is reactive; it does not proactively construct routes but constructs routes on demand. In the event of link breakages, SAT-MAODV employs the Energy Smart Transitivity (EST) technique to repair routes. The EST is an enhancement of the transitive routing method (Jaya et al., 2017). The transitive method is shown in Equation (1):

$$\forall A, B, C \in X, \text{ if } A \subset B \text{ and } B \subset C \text{ then } A \subset C \tag{1}$$

where $A, B, C =$ nodes with different energy level
$X =$ MCRAHN
$\subset =$ meeting likelihood (Jaya et al., 2017)

https://doi.org/10.18489/sacj.v35i2.17389

In Equation (1), if node A has a likelihood to be in the zone of node B and node B has a chance of encountering node C then we can infer that node A has a high probability of encountering node C. The transitive technique was first implemented in PRoPHET which was designed for routing in intermittent networks (Pathak et al., 2017). This routing technique relays packets through nodes with the highest probability of being in the destination node's zone in the event of route breakages or destruction.

The transitive technique was improved in our approach by including the energy factor. The traditional transitive method does not consider the energy of the nodes. It only relays packets based on the probability of encounters. In our proposed method, the EST is illustrated in Equation (2)

$$\forall A_{i1}, B_{i2}, C_{i3} \in X, \text{ if } A_{i1} \subset B_{i2} \text{ and } B_{i2} \subset C_{i3} \text{ then } A_{i1} \subset C_{i3} \tag{2}$$

if and only if $i3 \geq K$
where: $A, B, C =$ nodes
$i1, i2, i3 =$ different energy levels of nodes
$X =$ MCRAHN
$\subset =$ meeting likelihood
$K =$ threshold value

The EST improves the transitivity technique through the evaluation of the energy levels of nodes. When we infer that node A has a high likelihood of encountering node C, we first check the energy level of node C. If the energy level of node C is below the threshold value, then node A is not selected as a relay node since node C does not have sufficient energy to forward the packets. This is done to reduce the packet drop rate due to insufficient energy. The packet is instead relayed to the second-best node which is likely to move into the zone of the destination node or link node. This approach reduces RP delay and NR delay because in the case of route breakages, candidate nodes with a high likelihood to encounter the desired node are selected to repair routing paths. The technique increases the packet delivery ratio. EST does not waste bandwidth as most packets are delivered instead of being dropped. ICM, NRA and EST in SAT-MAODV are shown in Algorithm 1.

SAT-MAODV uses an integrated spectrum access technique referred to as Time-Based Availability (TBA). PU spectrum bands in some applications and technologies are deterministic and can be predicted. The PUs can utilise the spectrum at any time however, where usage patterns are predictable, spectrum usage can be modelled. Some spectrum bands are used at certain periods and are vacant at certain time intervals, for example, a day broadcaster or a regional broadcaster. SAT-MAODV uses TBA to first check the period when a spectrum band is required. The nodes then retrieve spectrum data of available bands during the required period. This approach reduces spectrum mobility delay since specific bands are considered instead of sensing several spectrum bands.

https://doi.org/10.18489/sacj.v35i2.17389

Algorithm 1 SAT-MAODV with ICM, NRA and EST techniques

for each node in the MCRAHN **do**
    if nodes encounter each other (1cm proximity) **then**
        Record the location in the buffer
    end if
end for
if node i_1 has to relay a packet to node l_{i2} **then**
    Send node l_{i2}'s location request to all the neighbouring nodes
    Two nodes with the highest encounters send the location record of node l_{i2}
end if
Let the network zone from source to destination be considered for centralized multi-cast
if there is route destruction in the selected network zone **then**
    if node $A_{i1} \subset$ node H_{i3} and node $H_{i3} \subset$ node l_{i2} **then**
        if $i3 > K$ **then**
            Let node X_{i1} relay packet to node H_{i3}
        else
            Let node i_1 buffer the packet
            Select the next node with a high encounter probability of node l_{i2}
        end if
    end if
end if

The TBA technique is modelled by Set 1:

$$S = \{s_1, s_2, \ldots, s_i\} \tag{Set 1}$$

where:
$S =$ set of spectrum bands availability states.

It is fundamental to note that since Set 1 is derived from the Markov chain model, the state of each spectrum band is not dependent on its predecessor's availability state. Each state is independent of its predecessor as shown in Equation (3):

$$k_{tm} = k_{tt}k_{mt} + k_{ti}k_{mi} + \cdots + k_{tm}k_{mm} \tag{3}$$

where:
$k_{tm} =$ the availability state of the spectrum channel
$k_{t\ldots} =$ the vacant spectrum channel when the routes are unavailable
$k_{m\ldots} =$ the vacant spectrum channel after route recovery

The main features of SAT-MAODV are ICM, NRA, EST and TBA. The relationship of SAT-MAODV and its optimisation is a multivariate linear regression model of four variables mod-

elled by Equation (4):

$$Y_i = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i \tag{4}$$

where:
Y_i = SAT-MAODV performance efficiency
α = intercept term for performance efficiency
β = the slope of the model
x_i = ICM
x_{i2} = NRA
x_{i3} = EST
x_{i4} = TBA
ε_i = Standard Error (constant)

The main features of SAT-MAODV are shown in Figure 1. The figure also shows how these features of SAT-MAODV interact in discovering and maintaining routes.

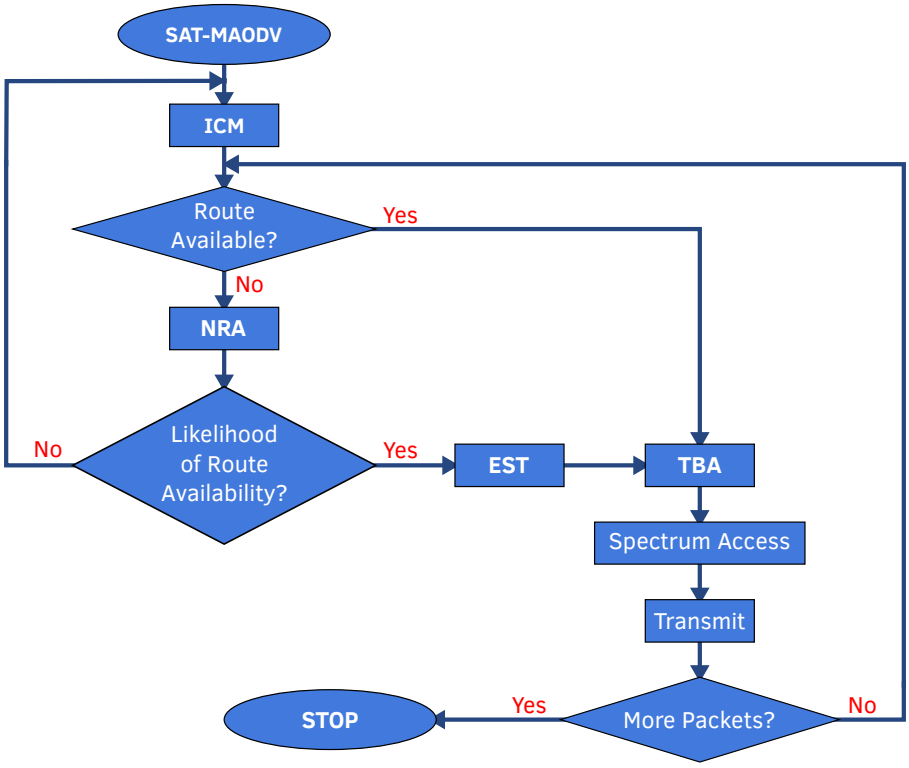


Figure 1: The discovery and the maintenance of routes in SAT-MAODV

Using the ICM, the SAT-MAODV first checks the availability of routes. If available, the TBA is evoked to facilitate the spectrum access under given constraints. Thereafter, the transmission can take place. If the route is not available, the NRA is used to determine the possibility

of a route being available given the node mobility and neighbourhood data. For this purpose, the transitivity technique, the EST is employed before executing the TBA. However, if there is no likelihood of a route, the scheme backs off and retries to establish the route later.

The simulation scenarios consisted of different network sizes with 6, 35 and 70 nodes and the protocols were simulated for 100, 300 and 500 simulation seconds respectively. The simulation durations were directly proportional to the number of nodes since more time was required to investigate the behaviour of each network. Table 1 presents the parameters used in the simulation environment.

Table 1: Simulation parameters

Number of SUs	6, 35, 70
Simulation Time(s)	100s, 300s, 500s
Maximum Number of connections	15, 25, 35
Pause Time(s)	0, 50, 100, 250, 350, 500
Number of Radios	2
Simulated Algorithms	SAT-MAODV, AODV, MAODV, xWCETT, MARSA
Antenna	Omni-directional
MAC Standard	IEEE 802.11b
Number of PUs	6 (For each set of nodes)
Number of SUs	4, 33, 68 (For each set of nodes)

SAT-MAODV integrates multi-cast with spectrum awareness, reactive, and transitive routing. The main features of the SAT-MAODV are the ICM, NRA, EST, and TBA. The performance of the SAT-MAODV algorithm was evaluated and compared to Ad hoc On-Demand Distance Vector (AODV), Multi-cast On-Demand Distance Vector algorithm (MAODV) (Jhajj et al., 2019), Extended Weight Cumulative Expected Transmission Time (xWCETT) (Kola & Velempini, 2018) and Mobility-Assisted Routing algorithm with Spectrum Awareness (MARSA) (Huang et al., 2014). The next section presents and discusses the comparative results of these algorithms.

4 RESULTS

The algorithms were simulated in network simulator 2 (NS 2) version NS2.31 with the CRAHN patch ported into NS 2.31. The occurrences of node destruction were randomised to create the MCRAHN environment and to simulate the performance of the schemes in MCRAHN. This enabled the study to effectively evaluate the proposed scheme.

Several reactive routing algorithms are considered in MCRAHNs however only the two best-performing algorithms according to the literature are compared to our proposed scheme (Kola & Velempini, 2016, 2017). The algorithms are the Multi-cast On-Demand Distance Vector algorithm (MAODV) (Jhajj et al., 2019), and the Extended Weight Cumulative Expected Trans-

mission Time (xWCETT) (Kola & Velempini, 2018). These are compared to our scheme, the Spectrum-Aware Transitive Multi-cast On-Demand Distance Vector (SAT-MAODV).

Figure 2 depicts the first set of simulation results: The performance of the xWCETT scheme is evaluated against MAODV to ascertain which is a better scheme. This was necessary because xWCETT was compared with WCETT and AODV (Kola & Velempini, 2016, 2017). MAODV is the improvement of AODV as such, there is a need for such investigation.

In the scenario with 6 nodes, the results show that xWCETT incurs more delay than MAODV. This can be attributed to the fact that the xWCETT behaves the same as the AODV in packet transmission. When a packet has to be relayed from source to destination the entire network is considered. In xWCETT, route request (RREQ) and route response (RRESP) packets are sent to all the nodes in the network while in MAODV a chosen sub-net or zone is flooded with RREQ and RRESP packets. The xWCETT scheme also utilises partial routes to broadcast RREQ and RRESP if nodes are destroyed in MCRAHNs. Partial routes are only discovered when the RREQ packet reports an error in that specific route. MAODV only considered the optimal and complete routes in a given zone (Doomari & Mirjalily, 2017). The MAODV scheme is a multi-cast while xWCETT is a broadcast algorithm. As a result, xWCETT is subjected to longer delays than the MAODV.

In scenarios with 35 and 70 nodes, the graphs are clustered and it is not clear which algorithm is more efficient. We then considered the performance averages of these algorithms in Figure 4 to better characterise them. The results show that in the scenario with 35 nodes, AODV outperformed xWCETT. However, in the one with 70 nodes, xWCETT outperformed MAODV. In the scenario with 35 nodes, the better performance of MAODV can be attributed to the reason presented for the scenario with 6 nodes. It is interesting to note that MAODV performs better in small networks and poorly in large networks largely because multi-cast is more effective in small networks. In large networks characterised by frequent network portions, it degrades. The occurrences of node destruction were randomised to simulate MCRAHN. It was also done to effectively evaluate the algorithms in MCRAHN.

Given the results in Figure 2 in which we concluded that MAODV was outperformed by the xWCETT, we then evaluated our proposed scheme against the xWCETT in Figure 3. However, we also considered the best-performing algorithm in each scenario and compared these two algorithms to our proposed algorithm, the SAT-MAODV.

Figure 3 results show that our proposed algorithm performs better than both the xWCETT and the MAODV in the respective scenarios and that the SAT-MAODV is more efficient.

In Figure 4, we can observe that our proposed algorithm, the SAT-MAODV, incurs the least RP delay. This can be attributed to the fact that SAT-MAODV uses transitive routing and a multi-cast approach. Node transitivity coupled with the direction of mobility helps SAT-MAODV ascertain which node is likely to be a relay or link node. The RP delay can be prolonged by nodes in a given zone which are moving away from the desired zone thereby portioning and degrading the performance of the network. The SAT-MAODV addresses the challenge through the transitive technique, history of encounters and use of the location data of nodes.

https://doi.org/10.18489/sacj.v35i2.17389

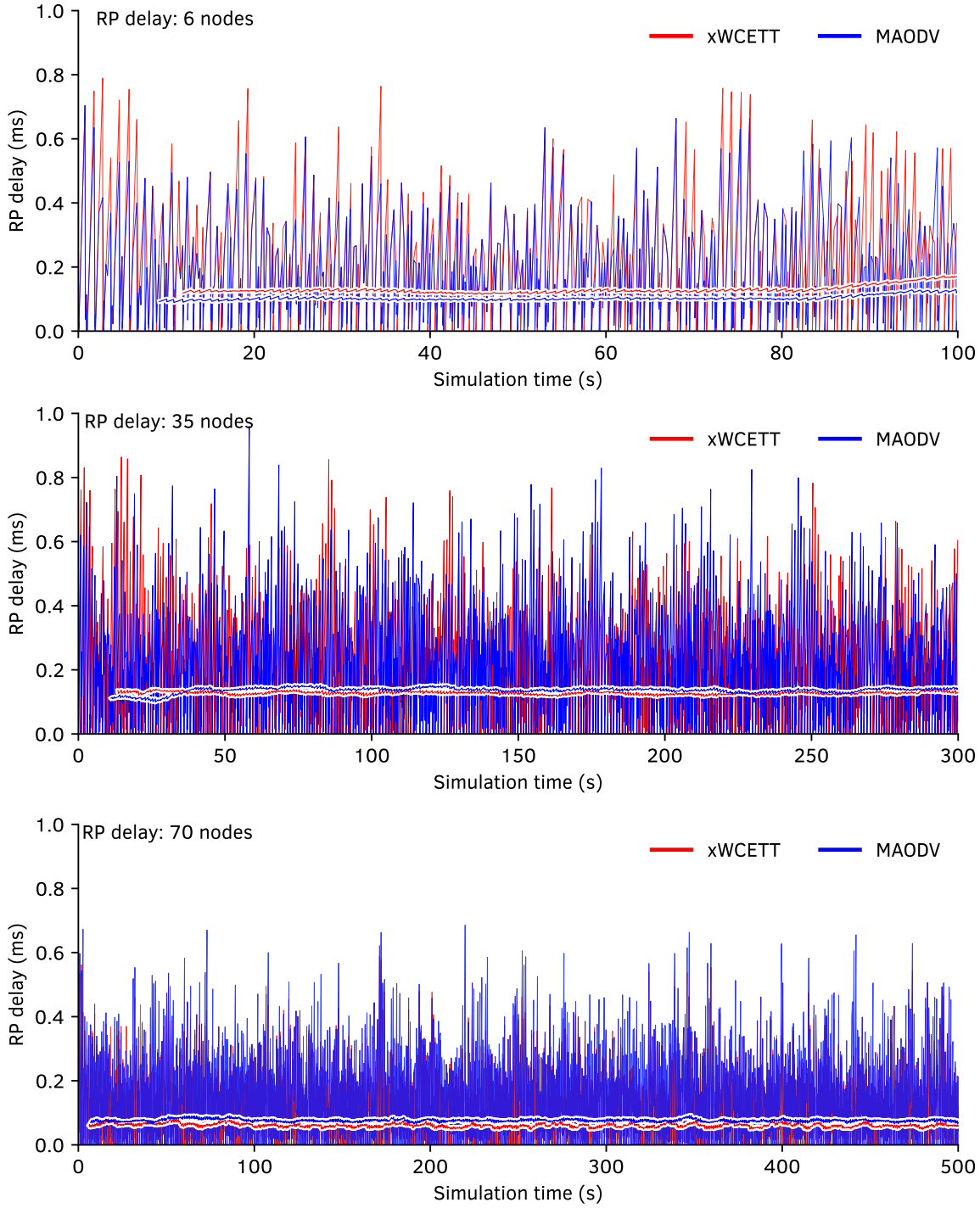


Figure 2: Comparative routing path delay results of xWCETT and MAODV. Moving averages overlaid to give an indication of the trends.

https://doi.org/10.18489/sacj.v35i2.17389

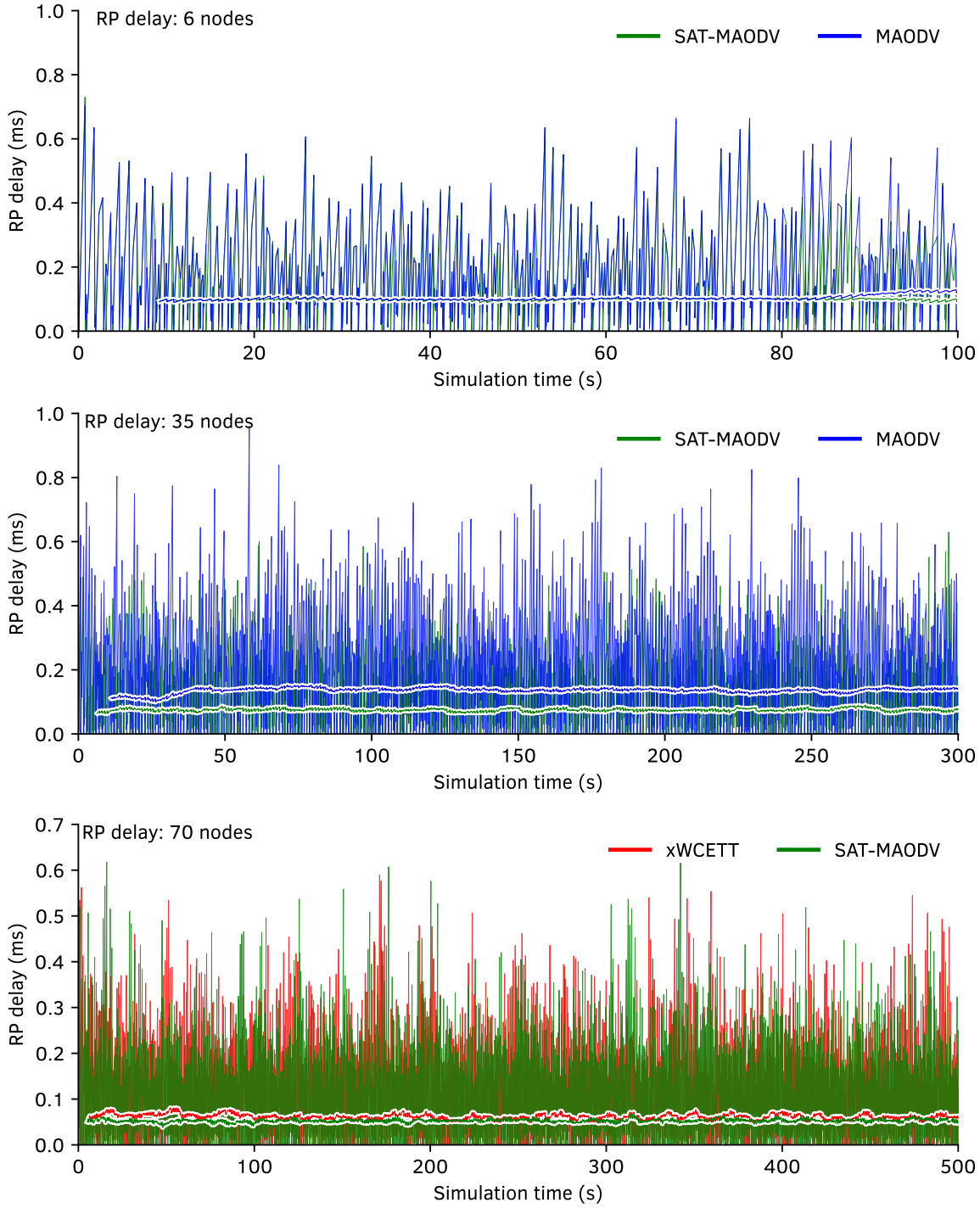


Figure 3: Comparative routing path delay results of xWCETT and SAT-MAODV. Moving averages overlaid to give an indication of the trends.

https://doi.org/10.18489/sacj.v35i2.17389

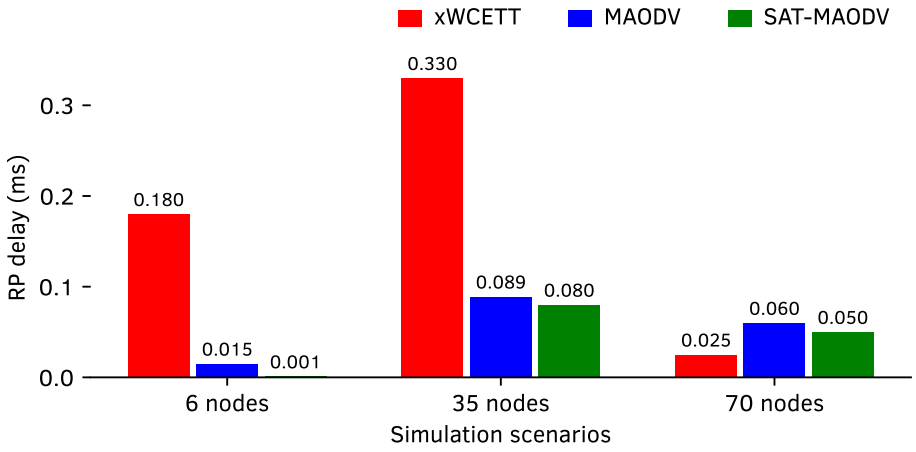


Figure 4: The average path delay results of xWCETT, MAODV, and SAT-MAODV

The other metric that we considered in our study is the NR delay. Figure 5 depicts the NR delay results of xWCETT, MAODV and SAT-MAODV. The results show that the SAT-MAODV is more efficient than the two algorithms while the average results of the three algorithms in Figure 4 provide more clarity in the analysis of the RP Delay results in Figures 2 and 3.

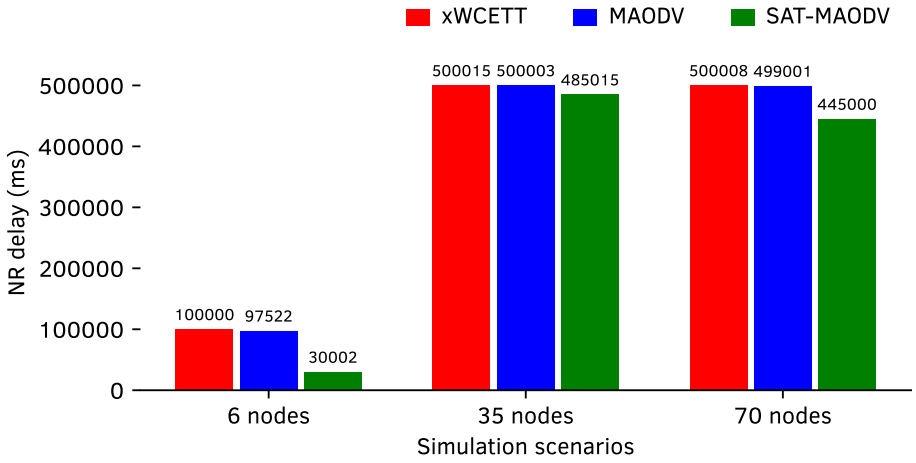


Figure 5: The node relay delay results of xWCETT, MAODV, and SAT-MAODV

The performance of SAT-MAODV is superior in NR delay because of the use of the Multi-cast (CM) and the Energy Infused Transitivity (EIT). In CM, packets are transmitted to specific zones (Nakhale & Khan, 2018). CM reduces NR delay because paths extending beyond the multi-cast group can be selected. In a complementary form, EIT is used to select the link or relay nodes with high residual energy.

The superiority of our scheme in delay can be observed in the scenario with 70 nodes in which delay slightly decreases instead of increasing. The NR delay is not solely dependent

on the number of nodes. The NR delay is still measured from one node to the next. It is a one-hop-related delay. The SAT-MOADV reduced the RP delay by at least 65% in comparison with xWCETT and by at least 11% when compared with MAODV. The NR delay results also show that the SAT-MOADV is the most efficient scheme. It reduced the node relay delay by 13% compared to xWCETT's performance and by at least 11% compared with MAODV.

We also evaluated the performance of the SAT-MAODV in terms of achievable throughput. Figure 6 depicts the achievable throughput of xWCETT and MAODV. The better scheme in this instance is compared to our proposed scheme, the SAT-MAODV in Figure 7.

In the scenarios with 6 and 35 nodes, MAODV outperforms xWCETT. The MAODV uses a faster destination location mechanism the "sequence numbers approach". The sequence numbers help in maintaining the routing tables and maintaining up-to-date routing information. MAODV discovers broken routes faster than xWCETT, in small networks which results in more achievable throughput as the broken routes are avoided. In a scenario with 70 nodes, xWCETT outperformed MAODV. We observed that where there is high PU and SU activity, and high node and spectrum mobility, xWCETT manages routing better. The xWCETT is designed for CRAHNs and it uses the expected transmission count (ETC) and the expected transmission time (ETT). It performs better in large CRAHNs (Kola & Velempini, 2018).

The ETC and ETT are used to select the best path based on path availability, the expected hops, and the time interval when the transmission is expected to take place. The ETT and ETC select the shortest path if the spectrum availability is guaranteed. The ETT and ETC increase the likelihood of the presence of the spectrum during transmission. This feature is effective in large networks like the case of the scenario with 70 nodes. The SAT-MAODV improved the achievable throughput by 31% in comparison with xWCETT and 17% compared with MAODV.

In Figure 7, SAT-MAODV was compared to the two algorithms based on the results in Figure 6. In scenarios with 6 and 35 nodes respectively, SAT-MAODV outperformed MAODV which was more efficient than xWCETT in Figure 6. SAT-MAODV uses energy infused transitivity approach. When a path is broken in a zone, a relay node is chosen using energy-infused transitivity and multi-casting techniques. It is optimised for high achievable throughput as it ensures that relay nodes have adequate energy to relay packets or to buffer packets until connectivity is re-established. In the scenario with 70 nodes, the SAT-MAODV outperformed the xWCETT however, the difference is marginal. This, however, demonstrates that the proposed scheme is efficient and performs well in both small and large networks.

4.1 The PDR results for SAT-MAODV and MARSA

The results in Figures 3 to 7 show that SAT-MAODV is more efficient than AODV, MAODV and xWCETT. In this section, we evaluate the performance of SAT-MAODV in comparison with MARSA. The two schemes were evaluated in terms of packet delivery ratio and latency. The MARSA results generated in (Huang et al., 2014) and the PDR results are shown in Figure 8.

In Figure 8, we can observe that SAT-MAODV outperformed MARSA in terms of packet delivery ratio results. The performance of SAT-MAODV can be attributed to the efficiency of

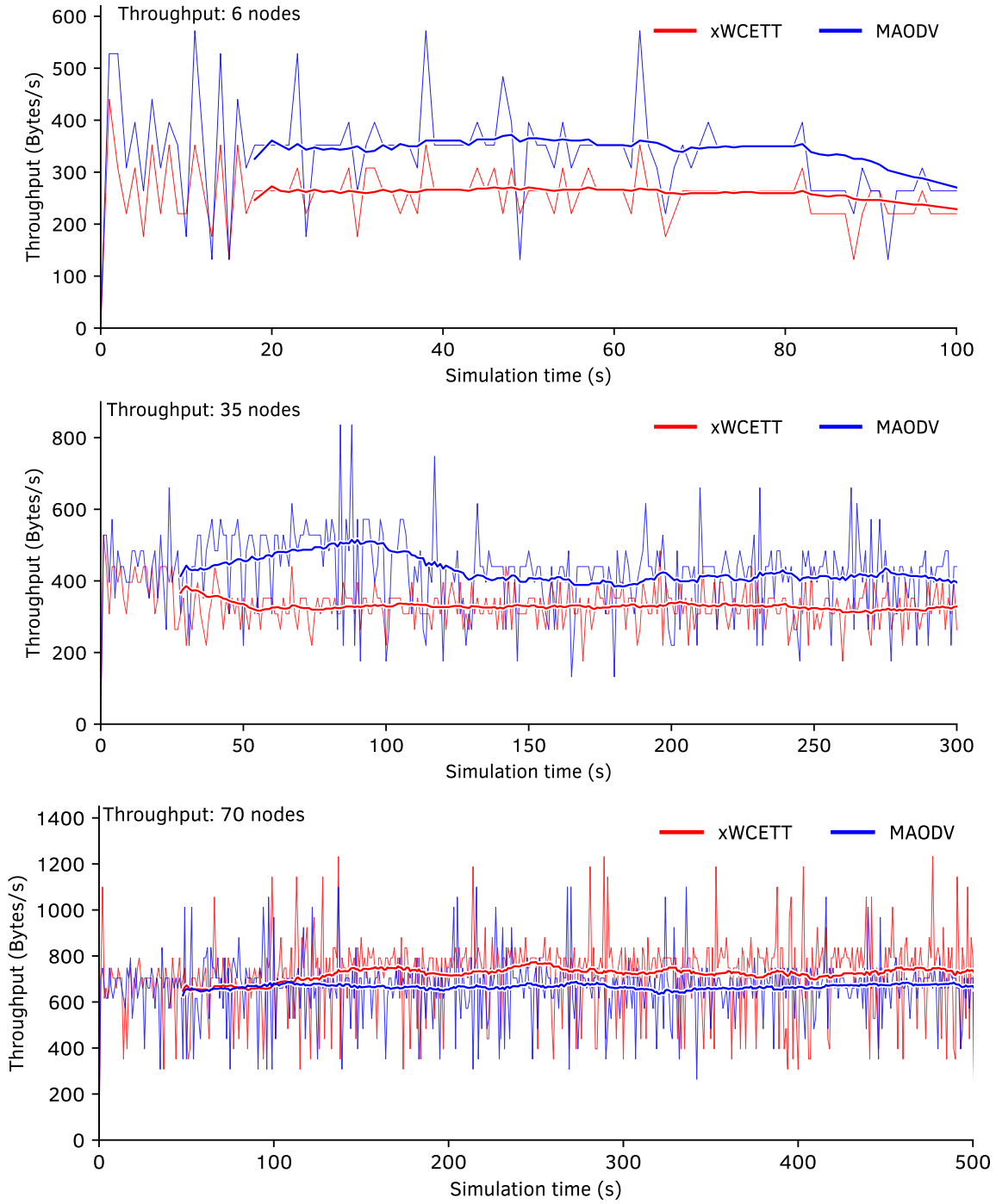


Figure 6: The achievable throughput results of xWCETT and MAODV. Moving averages overlaid to give an indication of the trends.

https://doi.org/10.18489/sacj.v35i2.17389

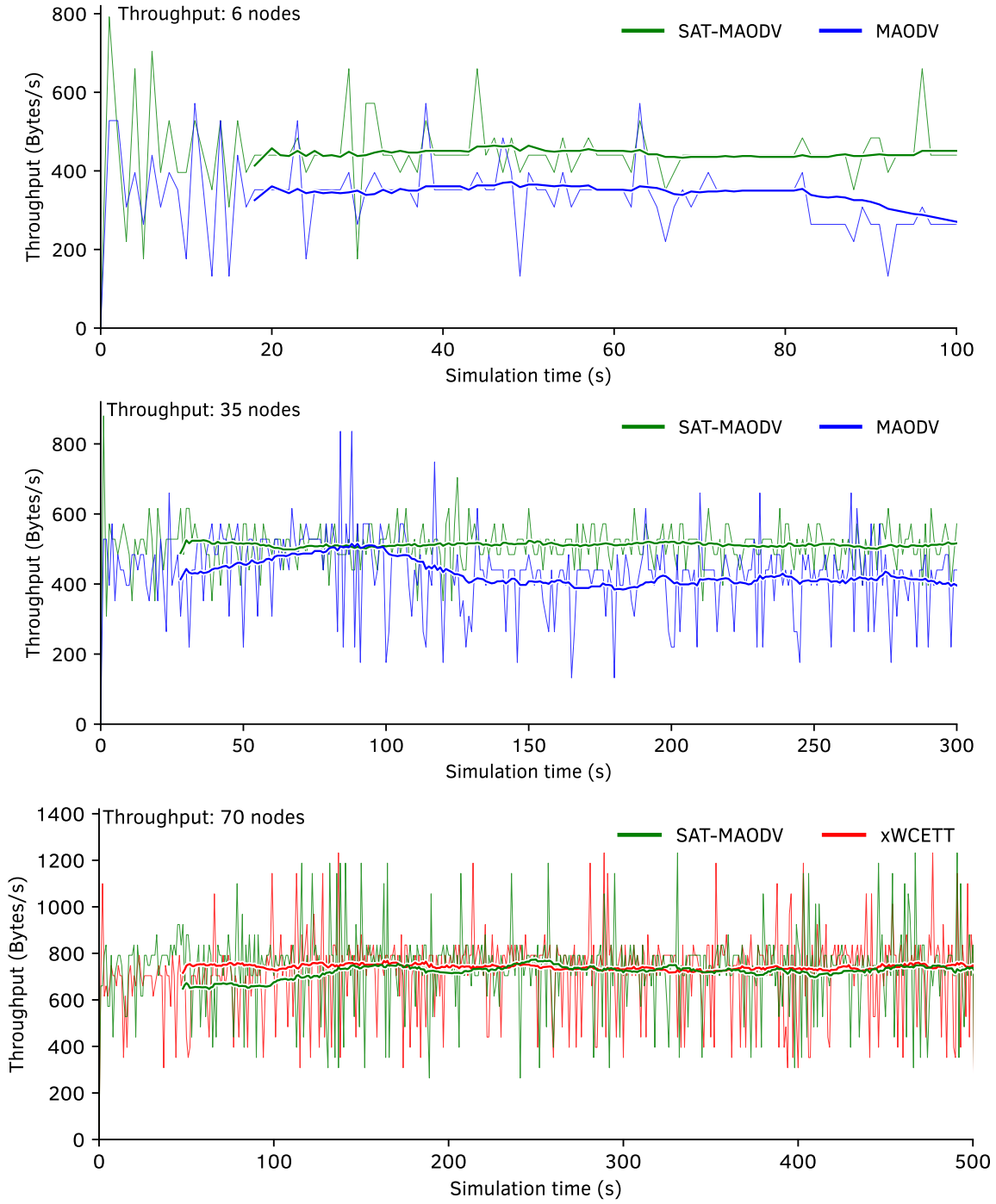


Figure 7: The achievable throughput results of xWCETT and SAT-MAODV. Moving averages overlaid to give an indication of the trends.

https://doi.org/10.18489/sacj.v35i2.17389

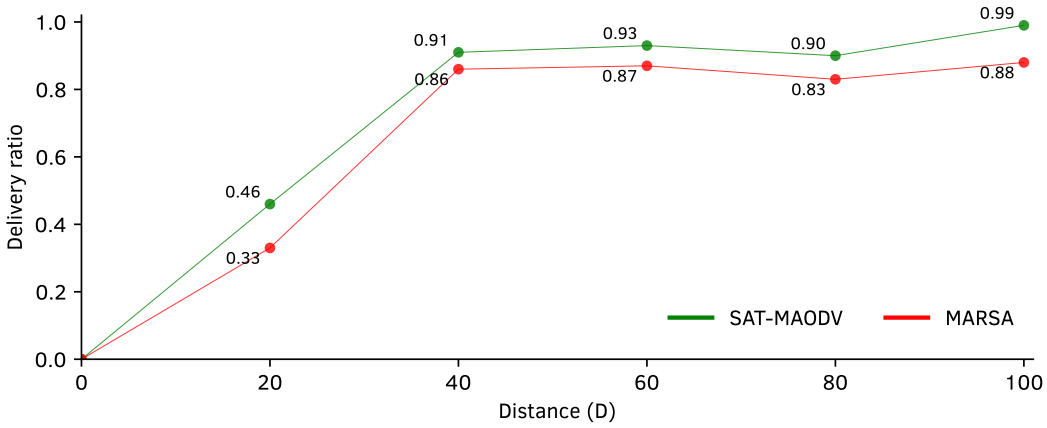


Figure 8: Packet delivery ratio simulation results for MARSA and SAT-MAODV

the transitivity technique. MARSA uses traditional buffering techniques to buffer packets. In cases where routes are unavailable, most packets for MARSA are timed-out. SAT-MAODV uses transitivity to relay packets to nodes with the highest likelihood to have an encounter with the destination nodes. The delivery ratio results show that SAT-MAODV improved the packet delivery ratio by 9% compared with MARSA. The latency results are shown in Figure 9.

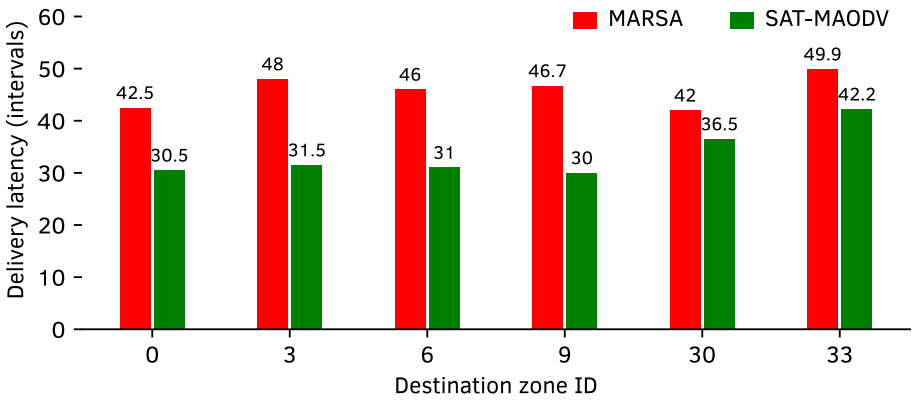


Figure 9: Delivery latency results of SAT-MAODV and MARSA

Figure 9 presents the latency results of SAT-MAODV and MARSA. We observe in the figure that SAT-MAODV incurred lower latency than MARSA for all the nodes. Delivery latency is closely linked to packet delivery ratio in terms of the factors contributing to its delay. If a packet takes too long in the network without being delivered, it results in a time-out. The delivery latency is inversely proportional to the packet delivery ratio. We observed that SAT-MOADV was superior to MARSA. It reduced the MARSA latency results by at most 27%.

The performance of SAT-MAODV is attributed to the transitivity technique which relays packets to nodes which are likely to move into the zone of the destination nodes. In the case

of MARSA, the packets are buffered until another route is re-established. The need for the re-establishment of routes sometimes is caused by spectrum mobility. As a result, packet delivery is delayed resulting in packets being lost or dropped.

5 CONCLUSION

The objective of the study was to address routing challenges in MCRAHNs. MCRAHNs is an intermittent network characterised by the destruction of nodes in combat which partitions the network. We proposed the SAT-MAODV scheme and evaluated its performance using the following metrics: RP delay, NR delay, SM delay, and throughput.

The performance of the proposed algorithm, the SAT-MAODV which consists of unique techniques such as the CM approach, Time based Spectrum Awareness, Transitive Routing and EIT, was compared with xWCETT, MAODV and MARSA. The results show that the SAT-MAODV is the best-performing algorithm and that it is efficient in both small and large networks. It degrades gracefully in large networks.

Node and spectrum mobility coupled with the destruction of nodes is still a challenge for the delay and latency-intolerant network technologies such as the fifth generation and the envisioned sixth generation of communication and beyond technologies. The efficiency of SAT-MAODV in route selection can be improved by incorporating the channel selection in the selection of the next hop based on the PU activity.

References

Ahmad, I., Shahabuddin, S., Kumar, T., Okwuibe, J., Gurtov, A., & Ylianttila, M. (2019). Security for 5G and beyond. *IEEE Communications Surveys & Tutorials*, *21*(4), 3682–3722. https://doi.org/10.1109/comst.2019.2916180

Akyildiz, I. F., Kak, A., & Nie, S. (2020). 6G and beyond: The future of wireless communications systems. *IEEE Access*, *8*, 133995–134030. https://doi.org/10.1109/access.2020.3010896

Amanowicz, M., Lenk, P., Zawiślak, W., Zbudniewek, J., Darakchiev, R., Krężel, J., & Michalski, M. (2012). *Military communications and information technology: A trusted cooperation enabler, Volume 2* (tech. rep.). Military University of Technology, Warsaw. https://www.yumpu.com/en/document/read/35521709/military-communications-and-information-technology-a-trusted-

Anushiya, P., & Suganthi, M. (2018). Energy detection based spectrum sensing data mining for safety-message delivery in CR enabled VANET. *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, 1130–1133. https://doi.org/10.1109/icisc.2018.8398979

Bouallegue, K., Dayoub, I., Gharbi, M., & Hassan, K. (2018). Blind spectrum sensing using extreme eigenvalues for cognitive radio networks. *IEEE Communications Letters*, *22*(7), 1386–1389. https://doi.org/10.1109/lcomm.2017.2776147

Bräysy, T., Tuukkanen, T., Couturier, S., Verheul, E., Smit, N., Buchin, B., Nir, V. L., & Krygier, J. (2017). Network management issues in military cognitive radio networks. *2017 International Conference on Military Communications and Information Systems (ICMCIS)*, 1–6. https://doi.org/10.1109/ICMCIS.2017.7956487

Deng, H., Wang, Y., & Wu, C. (2018). Cognitive radio: A method to achieve spectrum sharing in LTE-R system. *NOMS 2018 IEEE/IFIP Network Operations and Management Symposium*. https://doi.org/10.1109/noms.2018.8406208

Doomari, S. A., & Mirjalily, G. (2017). Interference modeling for energy aware geographical routing in cognitive radio ad hoc networks. *2017 3rd Iranian Conference on Intelligent Systems and Signal Processing (ICSPIS)*, 100–104. https://doi.org/10.1109/icspis.2017.8311597

Gharajeh, M. S. (2018). A neural-MCDM-based routing protocol for packet transmission in mobile ad hoc networks. *International Journal of Communication Networks and Distributed Systems*, *21*(4), 496. https://doi.org/10.1504/ijcnds.2018.095362

Guo, J., Ibrahim, A. A. I., Agaskar, A., Love, D. J., & Yazdani, N. (2018). Implementation of rate-adaptive integer forcing compression in distributed wireless relay networking. *2018 52nd Annual Conference on Information Sciences and Systems (CISS)*, 1–6. https://doi.org/10.1109/ciss.2018.8362202

Hrabcak, D., Matis, M., & Dobos, L. (2018). The concept of adaptive routing in cognitive radio mobile ad-hoc network. *2018 28th International Conference Radioelektronika (RADIOELEKTRONIKA)*, 1–6. https://doi.org/10.1109/radioelek.2018.8376380

Huang, J., Wang, S., Cheng, X., Liu, M., Li, Z., & Chen, B. (2014). Mobility-assisted routing in intermittently connected mobile cognitive radio networks. *IEEE Transactions on Parallel and Distributed Systems*, *25*(11), 2956–2968. https://doi.org/10.1109/tpds.2013.291

Jaya, T., Raaja, V. K., Sharanya, C., & Rajendran, V. (2017). An efficient power allocation and joint optimal sensing of spectrum in CDMA-based cognitive radio networks. *2017 International Conference on Communication and Signal Processing (ICCSP)*, 1769–1773. https://doi.org/10.1109/iccsp.2017.8286697

Jhajj, H., Datla, R., & Wang, N. (2019). Design and implementation of an efficient multipath AODV routing algorithm for MANETs. *2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC)*, 0527–0531. https://doi.org/10.1109/CCWC.2019.8666607

Ji, S., Yan, M., Beyah, R., & Cai, Z. (2015). Semi-structure routing and analytical frameworks for cognitive radio networks. *IEEE Transactions on Mobile Computing*, *15*(4), 996–1008. https://doi.org/10.1109/tmc.2015.2442250

Kaszuba-Chęcińska, A., Chęciński, R., Gajewski, P., & Łopatka, J. (2021). Cognitive radio MANET waveform design and evaluation. *Sensors*, *21*(4), 1052. https://doi.org/10.3390/s21041052

Khanmohammadi, S., & Gharajeh, M. S. (2017). A routing protocol for data transferring in wireless sensor networks using predictive fuzzy inference system and neural node. *Ad Hoc and Sensor Wireless Networks*, *38*(1-4), 103–124. https://www.oldcitypublishing.c

om/journals/ahswn-home/ahswn-issue-contents/ahswn-volume-38-number-1-4-2017/ahswn-38-1-4-p-103-124/

Khanmohammadi, S., & Gharajeh, M. S. (2018). An intelligent and knowledge-based overlapping clustering protocol for wireless sensor networks. *International Journal of Communication Systems*, *31*(10). https://doi.org/10.1002/dac.3577

Kola, L. M., & Velempini, M. (2018). The design and implementation of the XWCETT routing algorithm in cognitive radio based wireless mesh networks. *Wireless Communications and Mobile Computing*, *2018*, 1–8. https://doi.org/10.1155/2018/4173810

Kola, L. M., & Velempini, M. (2016). Performance analysis of extended weighted cumulative expected transmission time (xWCETT) routing protocol in cognitive radio wireless mesh networks. *2016 International Conference on Advances in Computing and Communication Engineering (ICACCE)*. https://doi.org/10.1109/icacce.2016.8073726

Kola, L. M., & Velempini, M. (2017). A model to improve the routing performance of cognitive radio wireless mesh networks. *South African Computer Journal*, *29*(3), 64–80. https://doi.org/10.18489/sacj.v29i3.524

Kumar, R. (2018). Distributed algorithms for opportunistic spectrum access in decentralized cognitive radio network. *2018 10th International Conference on Communication Systems & Networks (COMSNETS)*. https://doi.org/10.1109/comsnets.2018.8328259

Lee, K., Park, J. G., & Yoo, S.-J. (2021). Intelligent cognitive radio ad-hoc network: Planning, learning and dynamic configuration. *Electronics*, *10*(3), 254. https://doi.org/10.3390/electronics10030254

Nakhale, D., & Khan, M. Z. A. (2018). Fast binary power allocation for uplink distributed cognitive radio networks. *2018 10th International Conference on Communication Systems & Networks (COMSNETS)*, 435–438. https://doi.org/10.1109/comsnets.2018.8328237

Onem, E., Eryigit, S., Tugcu, T., & Akurgal, A. (2013). QoS-enabled spectrum-aware routing for disaster relief and tactical operations over cognitive radio ad hoc networks. *MILCOM 2013 IEEE Military Communications Conference*, 1109–1115. https://doi.org/10.1109/milcom.2013.191

Pathak, S., Gondaliya, N., & Raja, N. (2017). A survey on PROPHET based routing protocol in delay tolerant network. *2017 International Conference on Emerging Trends & Innovation in ICT (ICEI)*, 110–115. https://doi.org/10.1109/etiict.2017.7977020

Sabbah, A., Ibnkahla, M., Issa, O., & Doray, B. (2018). Control channel selection techniques in cognitive radio networks: A comparative performance analysis. *Journal of Communications and Networks*, *20*(1), 57–68. https://doi.org/10.1109/jcn.2018.000006

Suojanen, M., & Nurmi, J. (2014). Tactical applications of heterogeneous ad hoc networks – cognitive radios, wireless sensor networks and COTS in networked mobile operations. *COCORA 2014 - The Fourth International Conference on Advances in Cognitive Radio*, 1–5. http://personales.upv.es/thinkmind/COCORA/COCORA_2014/cocora_2014_1_10_80004.html

Tang, H., & Watson, S. (2014, December). *Cognitive radio networks for tactical wireless communications* (tech. rep. No. DRDC-RDDC-2014-R185). Defence Research and Development Canada. https://apps.dtic.mil/sti/citations/AD1004297

Tayel, A. F., & Rabia, S. I. (2018). A new probabilistic target channel selection approach for load balancing in cognitive radio networks. *IEEE Transactions on Cognitive Communications and Networking*, *4*(1), 43–52. https://doi.org/10.1109/tccn.2017.2780840

Tegou, T. I., Tsiflikiotis, A., Vergados, D. D., Siakavara, K., Nikolaidis, S., Goudos, S. K., Sarigiannidis, P., & Obaidat, M. (2018). Spectrum allocation in cognitive radio networks using chaotic biogeography-based optimisation. *IET Networks*, *7*(5), 328–335. https://doi.org/10.1049/iet-net.2017.0264

Towhidlou, V., & Shikh-Bahaei, M. (2018). Improved cognitive networking through full duplex cooperative ARQ and HARQ. *IEEE Wireless Communications Letters*, *7*(2), 218–221. https://doi.org/10.1109/lwc.2017.2766143

Tuukkanen, T., Couturier, S., Buchin, B., Braysy, T., Krygier, J., Verheul, E., Nir, V. L., & Smit, N. (2018). Assessment of cognitive radio networks through military capability development viewpoint. *2018 International Conference on Military Communications and Information Systems (ICMCIS)*. https://doi.org/10.1109/icmcis.2018.8398691

Tuukkanen, T., Couturier, S., Buchin, B., Bräysy, T., Krygier, J., Verheul, E., Nir, V. L., & Smit, N. (2018). Assessment of cognitive radio networks through military capability development viewpoint. *2018 International Conference on Military Communications and Information Systems (ICMCIS)*, 1–8. https://doi.org/10.1109/icmcis.2018.8398691

Wen, Y., Jing, T., Huo, Y., Li, Z., & Gao, Q. (2018). Secrecy energy efficiency optimization for cooperative jamming in cognitive radio networks. *2018 International Conference on Computing, Networking and Communications (ICNC)*, 795–799. https://doi.org/10.1109/iccnc.2018.8390398

SACJ 35(2) December 2023
Research Article

The Influence of Change Management Process on Cloud Transitioning

Rito Miyen, Carl Marnewick

Department of Applied Information Systems, University of Johannesburg, South Africa

ABSTRACT
Technology is a dynamic field with constant changes, improvements, and new discoveries even before anyone is fully comfortable or used to the way it was. Cloud computing has gained momentum with the migration to the cloud growing at an incremental rate each year. However, some organisations migrate prematurely without fully understanding the impact on various factors. This research focuses on the influence of change management processes on cloud transitioning. The study included the feasibility of using COBIT to adequately manage organisational change when migrating to the cloud. The quantitative research methodology used a survey where the concept of cloud computing and applying COBIT in the context of organisational change were explored. A combination of these concepts was necessary as these had not been explored in other studies. A correlation coefficient analysis was performed to determine the relationship between COBIT's change management processes and the success rate of cloud computing. The results of this research suggest that there is a relationship between change management processes and the success rate of cloud computing. Future research could include the creation of a cloud-readiness assessment model to assist businesses to make an informed decisions when migrating to the cloud.

Keywords IT governance, Cloud computing, Change management, COBIT

Categories • **Computer systems organisation** ∼ **Architectures, Distributed architectures, Cloud computing**

Email
Rito Miyen – miyen.nr@gmail.com,
Carl Marnewick – cmarnewick@uj.ac.za (CORRESPONDING)

Article history
Received: 19 May 2022
Accepted: 1 September 2023
Online: 14 December 2023

1 INTRODUCTION

For various reasons, organisations are transitioning to cloud computing at an increasing rate each year (Akar & Mardiyan, 2016). Some organisations are transitioning to the cloud for monetary benefits, whilst others are migrating to increase the efficiency and effectiveness of their internal processes (Akar & Mardiyan, 2016; Gimmon & Benjamin, 2014). This transition has presented businesses with a level of unprecedented agility, improving the organisations' ability to implement and deliver fast and effective services (Almishal & Youssef, 2014; Narula et al., 2015). However, cloud transition has also introduced new challenges to organisations' risk, governance and management strategies, as those strategies attempt to protect information

Miyen, R., and Marnewick, C. (2023). The Influence of Change Management Process on Cloud Transitioning. *South African Computer Journal* 35(2), 25–49. https://doi.org/10.18489/sacj.v35i2.17441

ISSN 1015-7999 (print) ISSN 2313-7835 (online)

in an environment where they have minimal control (Narula et al., 2015). This results in many organisations resorting to cloud computing to handle such challenges (Singh, 2012). However, some organisations are prematurely moving to the cloud without careful consideration of the effects of this transition.

Change management and IT are inseparable. The implementation of any new IT system or the upgrade of such systems, involves change. Change is associated with (1) the way and manner that people engage with the new system (behavioural) and (2) the introduction of new or enhanced business processes (system). Whether the change is behavioural or system, it should have a positive impact. Change management can be addressed from various angles. Changing behaviour speaks to the culture of the organisation. Various studies have focused on behavioural changes, for instance Kotter's (1995) 8-step change methodology. Jayeola et al. (2022) discussed the role of top management in the adoption of enterprise resource planning (ERP) cloud solutions. Da Veiga (2018) introduced the Prosci's ADKAR (Awareness, Desire, Knowledge, Ability and Reinforcement) change management model to investigate culture change regarding security. Even information systems theories such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) address this phenomenon, ensuring that users adopt and adapt to changes. From a process perspective, Hornstein (2015) highlighted the symbiotic relationship between change management and project management. Change management is also a component of IT service management (Gacenga et al., 2010). Here the focus is on standardised methods and procedures that are used for the efficient and prompt handling of all changes to control IT infrastructure.

Irrespective of the change management perspective, change is governed through corporate governance as well as IT governance. From a corporate governance perspective, the King IV Report on Good Governance stipulates that the oversight should be exercised resulting in "a technology architecture that enables the achievement of strategic and operational objectives" (Institute of Directors Southern Africa, 2016). IT governance forms part of corporate governance and the major approaches include the Control Objectives for Information and Related Technologies (COBIT), the Information Technology Infrastructure Library (ITIL) and International Standards Organisation Standard on IT governance (ISO 38500:2015).

In general, the concerns of cloud computing have become so significant that studies suggest cloud computing may have a distinct governance function, separate from other governance capabilities (Narula et al., 2015; Rebollo et al., 2015). Researchers have gone as far as suggesting that some organisations need a specific executive position that is committed to the oversight of cloud-related issues, such as a Chief Cloud Officer, and a separate subcommittee from the board of directors to guide the position's priorities (Gimmon & Benjamin, 2014).

Organisations' transition to the cloud involves change from a behavioural and a systems perspective. The research question posed by this study is: *whether change management processes have any influence on the success of cloud transitioning*. This will be analysed from the systems perspective. In this study, COBIT was used as the IT governance framework. The choice of COBIT is based on the following: it is a globally recognised framework and it provides measurable and actionable practices through its various control objectives (Erasmus & Marnewick,

2021). Insights were gathered from IT managers and IT executives within the South African banking sector with relevant experience in cloud computing, IT governance and change management.

The outline of this article is as follows: Section 2 focuses on the literature studied in this research i.e., the concept of cloud computing, IT governance and organisational change management within the context of cloud transitioning. Section 3 focuses on the research methodology used in this research – it explores the concept of research and how to determine the appropriate research method to use for this study. Section 4 focuses on the data analysis and discussion – it discusses how the data were collected, analysed, and interpreted. The results of this section provide insights needed to determine if the research goal was met. Section 5 concludes this research study by revisiting the objectives and determining the outcome.

2 LITERATURE REVIEW

'The cloud' is a concept that has been around since the 1990s. Haris and Khan (2018) did an extensive mapping around the paradigm of cloud computing. The origins of cloud computing as we know it today, originated from distributed computing, evolved into cluster computing, and eventually cloud computing. The underlying premise is that cloud simply refers to the internet and its supporting infrastructures (Conway & Curry, 2012; Marston et al., 2011). Cloud computing is a model that enables network access to shared computing resources that can be managed with minimal effort or minimal service provider interaction, from anywhere at any time. Cloud computing is mainly based on internet computing where virtual resources are used on a pay-as-you-use basis (Thobejane & Marnewick, 2020). Cloud computing can also be defined as internet-based computing in which virtual resources are dynamically scaled and provided as infrastructure, platform or service, over the internet (Singh, 2012). In this article, cloud computing is defined as the sharing of virtual resources and dynamically managing them, ubiquitously over the internet.

Figure 1 depicts a high-level summary of cloud computing (Thobejane & Marnewick, 2020). Cloud computing consists of various deployment models, service models and essential characteristics. Cloud computing essentially has five characteristics, namely resource pooling, broad network access, rapid elasticity, measured service and on-demand self-service (Armbrust et al., 2010).

The various deployment models are adopted by different organisations based on business needs and other related factors. There are different types of cloud deployment models. Deploying these cloud models can happen in the following ways, namely private cloud, public cloud, community cloud and hybrid cloud (Subashini & Kavitha, 2011). Selecting a deployment model may be based on a variety of factors, ranging from business objectives to how the business is structured, taking into consideration the benefits and drawbacks of the model adopted:

- Private cloud refers to computing resources that are used, controlled and owned by an

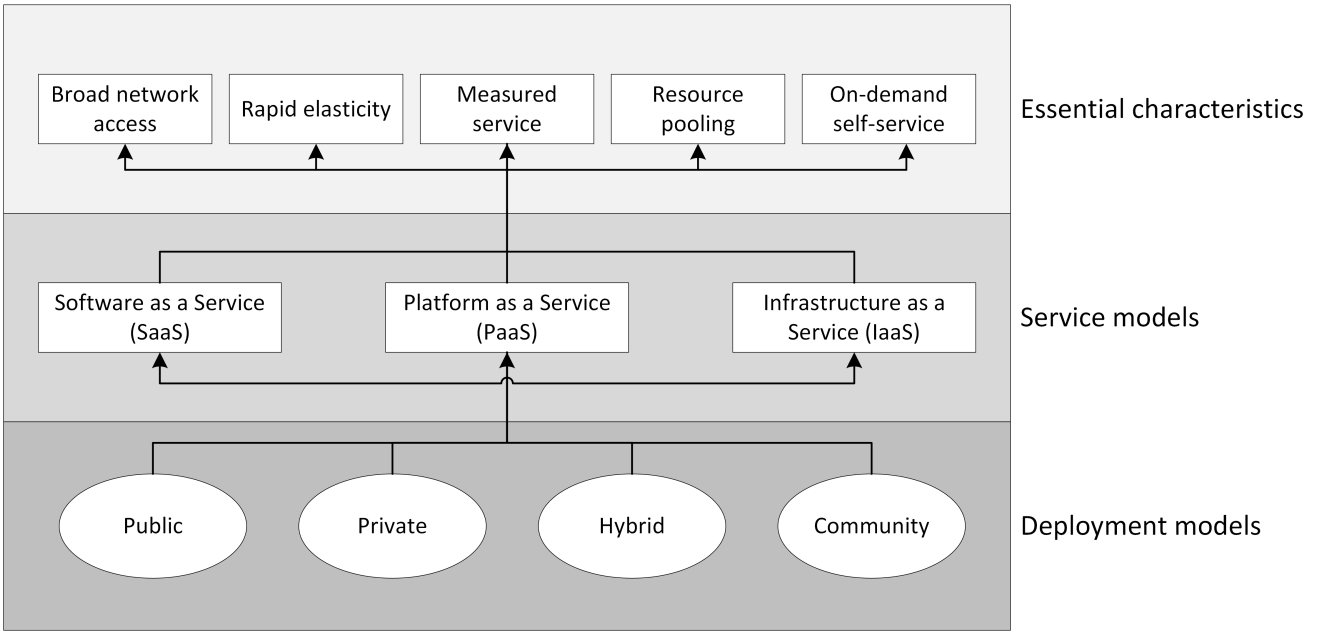


Figure 1: Summary of cloud computing[a]

[a](Thobejane & Marnewick, 2020)

organisation (Leavitt, 2009). Hosting can either be internal, within the organisation, or external, through a third party or a cloud service provider (CSP).

- Public cloud refers to computing resources that are owned and managed by third parties or cloud providers (Mell & Grance, 2011). The resources are dynamically provisioned over the internet. There is the ability to scale resources up or down as needed by the organisation.
- Community cloud refers to organisations in a group with common interests alongside their concerns and share computing resources. The infrastructure is arranged and maintained by third-parties or CSPs, and the organisations involved (Mell & Grance, 2011).
- Hybrid cloud refers to when an organisation has a desire to provide cloud services but would still like to secure its internal workings. Hybrid cloud hosting could be from within or outside the organisation, based on the objectives of opting to use a hybrid cloud.

In summary, the various deployment models can be compared as per Table 1.

Once an organisation has decided which deployment model to adopt, they then need to consider the service model that they will use i.e., infrastructure as a service (IaaS), platform as a service (PaaS) and/or software as a service (SaaS). These sometimes build on one another but can also be independent from each other. Figure 2 gives an overview of the cloud service mod-

Table 1: Summary of cloud deployment models[abc]

Deployment model	Reason for adoption	Cloud setup	Benefits	Drawbacks
Private Cloud	- Privacy and legal reasons - Smooth running of private data centres - Availability of computational resources	- Hosting can either be internal or external, based on usage - Infrastructure is owned and controlled by an organisation	- Exposure is better managed, thus more reliable and secure	- Purchase and maintenance of infrastructure might be costly
Public Cloud	- Requires variable resources - Inability to purchase and maintain infrastructure - Collaborative development projects - Variety of resource services available at low costs based on usage	- Infrastructure is setup by a cloud service provider	- Pay as you use, thus low cost - Resources are dynamically provisioned over the internet - Scalable and transitioning between performance immediately and with ease	- Risk of exposure is high, thus security concerns - The higher the scalability, the higher the cost
Commmunity Cloud	- Organisations grouped together with common interests and concerns	- Infrastructure is setup and maintained by 3rd parties, or organisations involved	- Collaboration and sharing with other organisation - Lower cost of investment	- Very slow adoption rate, this is only beneficial once more organisations are involved
Hybrid Cloud	- Organisation with the desire to provide cloud services, but also wants to safeguard its internal workings	- Cloud hosting may be from within or outside based on the usage requirement	- Enable organisations to enjoy the benefits of being scalable with minimal costs of public cloud, whilst still reducing exposure of critical applications to third party vulnerabilities	- Not easy to maintain - Infrastructure is dependent on one another and the merging of many cloud platforms

[a]Mell and Grance (2011)
[b]Hentschel et al. (2021)
[c]Rastogi and Sushil (2015)

els, depicting how the models build on each other. It also indicates where the responsibility lies i.e., who manages the cloud.

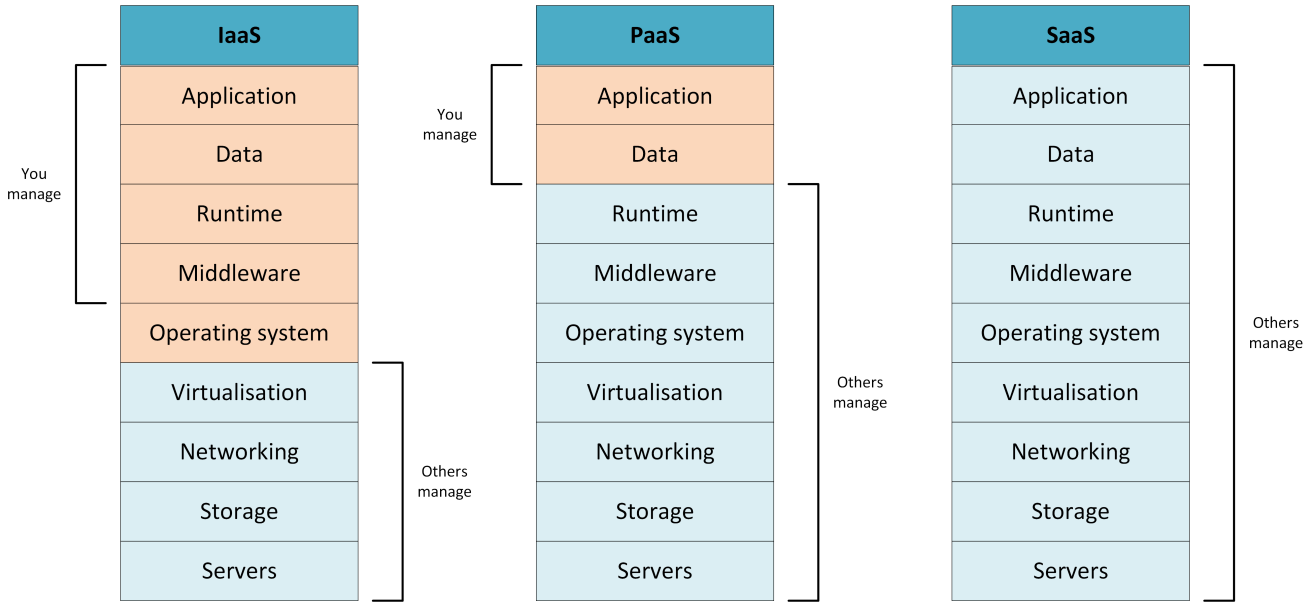


Figure 2: Cloud service models[ab]

[a]Marston et al. (2011)
[b]Thobejane and Marnewick (2020)

Over the years, cloud computing has gained momentum, and has been growing incrementally ever since its inception. There have been three major role players, namely Amazon with its Amazon Web Services, Microsoft with its Microsoft Azure, and Google with its Google Cloud Platform (GCP) (Almishal & Youssef, 2014; Conway & Curry, 2012). These three players have most of the global cloud market. The three role players in cloud computing have penetrated the market over the years and occupy specific segments. They have continued to grow at an incremental rate and gain market-share across the world (Gimmon & Benjamin, 2014).

Various benefits and challenges are associated with cloud computing. The benefits of cloud computing can be grouped into non-functional, economic and technology benefits. Non-functional benefits include simplicity, elasticity/scalability, mobility, and availability. Economic benefits include the reduction of cost, pay-per-usage, and a green environment (sustainability). Technological benefits include virtualisation, multi-tenancy, security, and data management. Saini et al. (2019) added the following benefits: backup and recovery, speed of setup and growth in business. Marston et al. (2011) mentioned that lowering IT barriers to innovation is also a benefit of cloud computing. Table 2 classifies the benefits of cloud computing.

The two major benefits of cloud computing are the scalability associated with cloud computing and the reduction of cost.

https://doi.org/10.18489/sacj.v35i2.17441

Table 2: Benefits of cloud computing

Classification	Benefit	References
Non-functional	Simplicity	Haris and Khan (2018)
	Elasticity/scalability	Akar and Mardiyan (2016), Singh (2012), Haris and Khan (2018), Marston et al. (2011), Leavitt (2009), Saini et al. (2019)
	Mobility	Haris and Khan (2018), Marston et al. (2011)
	Availability	Haris and Khan (2018), Marston et al. (2011)
Economic	Cost reduction	Singh (2012), Haris and Khan (2018), Marston et al. (2011), Saini et al. (2019)
	Pay-per-usage	Haris and Khan (2018)
	Green environment (sustainability)	Singh (2012), Haris and Khan (2018), Youssef (2014)
Technological	Virtualisation	Haris and Khan (2018), Saini et al. (2019)
	Multi-tenancy	Singh (2012), Haris and Khan (2018)
	Security	Singh (2012), Haris and Khan (2018), Saini et al. (2019)
	Data management	Haris and Khan (2018), Saini et al. (2019)
	Backup & recovery	Saini et al. (2019)
	Speed of setup	Marston et al. (2011), Saini et al. (2019)
	Business growth	Saini et al. (2019)
	Innovation	Marston et al. (2011)

The benefits of adopting cloud computing out-weighs the disadvantages associated with cloud computing. Disadvantages of cloud computing include load balancing performance interoperability energy consumption (Haris & Khan, 2018) security staffing or resource reduction (Saini et al., 2019; Stein et al., 2020).

Cloud computing brings various changes about within an organisation. These changes relate to infrastructure, processes, project management, roles and responsibilities of people, governance and legislation (Borgman et al., 2013; Li et al., 2010; Rizescu & Tileaga, 2016). These changes can be classified as either behavioural or system. In addition, these changes need to be managed effectively to ensure the introduction of cloud computing adds value within an organisation (Gimmon & Benjamin, 2014).

2.1 Organisational change as a result of cloud computing

The transition to cloud computing introduces change. From an IT perspective, the ability to effectively manage change has emerged as a pivotal skill in navigating the complexities of today's dynamic business environment. Change management can be defined as a structured approach to transitioning individuals, teams, and entire organisations from a current state to a desired future state, minimising resistance and maximising the likelihood of success.

Numerous theories and models have been developed to provide frameworks for understanding and implementing change within organisations. One of the most widely known models is Lewin's Change Management Model (Ratana et al., 2020), which suggests that change involves

three stages: unfreezing the current state, transitioning to the desired state, and refreezing to stabilise the new state. This model underscores the importance of preparing employees for change, managing the transition, and reinforcing new behaviours. Another influential framework is Kotter's (1995) 8-Step Change Model, which emphasises creating a sense of urgency, forming a guiding coalition, developing a vision, communicating the vision, empowering action, generating short-term wins, consolidating gains, and anchoring new approaches in the culture. This model places a strong focus on leadership's role in driving change and ensuring its sustainability. This model is aimed at the strategic level of the change management process (Tang, 2019). The ADKAR model is mainly intended to be a coaching and change management tool to assist subordinates through the change process within organisations (Tang, 2019). The ADKAR model describes how change can be successful at an individual level. Da Veiga's (2018) study investigated the role of an individual's behaviour on information security. These change management theories focus on the culture and behavioural changes within the organisation. In this study, the focus is on the governance of changes associated with the transition to the cloud. The focus is not on the individual or organisation per se.

From an IT perspective, change management holds particular significance. Rapid technological advancements and digital transformations are common in the IT landscape, making effective change management essential to ensure the success of projects and minimise disruptions. ITIL is a widely adopted framework that provides best practices for IT service management, including change management (Marrone & Kolbe, 2011). ITIL emphasises the importance of rigorously planning and controlling changes to IT services, evaluating risks, and involving relevant stakeholders throughout the process.

Agile and DevOps methodologies introduced new approaches to change management in IT (Marnewick & Langerman, 2021). These methodologies promote iterative development, continuous integration, and frequent releases, necessitating a more flexible and adaptable change management strategy. This shift from traditional waterfall approaches to more dynamic methods aligns change management with the pace of technological innovation (Tshabalala & Marnewick, 2021).

Change is inherent to the world of technology, with organisations constantly adopting new systems, software, and processes to remain competitive and efficient. COBIT, within its governance structure, plays a pivotal role in change management by providing a structured framework for evaluating, approving, and implementing changes to an organisation's IT environment. COBIT ensures that changes are in line with the organisation's strategic objectives and are implemented in a controlled and risk-aware manner. By setting up change governance processes and defining the roles and responsibilities of stakeholders, COBIT establishes a framework for assessing the impact of changes on business outcomes and IT systems. By incorporating change management principles that align with COBIT's guidelines, organisations can drive innovation, enhance operational efficiency, and minimise risks associated with technology transformations.

Organisational change comes with various benefits when businesses decide to move to the cloud. These benefits ensure that these organisations remain relevant in the long term and can

sustain their businesses. When organisations change because of cloud computing, the benefits can be summarised as follows (Gimmon & Benjamin, 2014; Li et al., 2010):

Increased return on investment An organisation embarking on an organisational change, usually invests many resources to ensure the implementation of an effective change. In the case of cloud computing, organisations can share their resources with others to save costs and pay only for what they use.

Improved productivity Organisational change could be a result of automating mundane business processes. In the case of cloud computing, organisations do not need staff working on upgrading the infrastructure and manually updating software in their data centres; all these can be automated, and the staff can focus on other fulfilling tasks.

Greater efficiency Organisational change could be due to decommissioning legacy systems that require repetitive, tedious processes to conduct business. In the context of cloud computing, the performance of the systems and availability of services is determined by the SLA between the organisation and their CSP, thus better efficiency can be achieved by subscribing to the correct package.

Reduced costs Organisational change could be from improving processes to reduce organisational costs. In the context of cloud computing, not having a data centre that requires maintenance within the organisation could save costs

New opportunities Any change comes with new opportunities. In the context of cloud computing, an organisation having the ability to store more data about their clients and gain some insights about their behavioural patterns could result in opportunities that they never knew existed.

However, just like any other concept, organisational change as a result of cloud computing comes with challenges as well (Akar & Mardiyan, 2016; Rizescu & Tileaga, 2016):

Conflict As many as there are people who embrace change, there are just as many who are reluctant to change. In the context of cloud computing, conflict could arise from some maintenance staff members being retrenched as a result of not needing an in-house data centre.

Distinguishing the necessity of different objectives For a change to occur, there needs to be a vision that drives this change. However, if the vision is not communicated effectively, it could result in stakeholders misunderstanding the need for the change. In the context of cloud computing, some stakeholders might think the reason for moving to the cloud is to restructure and retrench some staff members, which could lead to disgruntled employees who do not fully understand the vision.

https://doi.org/10.18489/sacj.v35i2.17441

Maintaining records of the acceptance of change Organisational change needs to be tracked and constantly monitored. With cloud computing, if the organisation successfully migrates to the cloud, but migration hinders business processes that support daily operations, then there must be a way to measure this and be able to resolve it timeously.

Planning Organisational change requires intensive planning, constant monitoring and updating of the plan, based on different challenges that could possibly arise. In cloud computing, if the organisation plans on using a CSP based on what was discussed and agreed on, only to find that this does not really have all the services that the organisation needs, one should reconsider and look at alternative options offered by other CSPs.

Cloud computing brings about change in an organisation. These changes include the infrastructure, processes, project management, roles and responsibilities of people, governance and legislation (Borgman et al., 2013; Li et al., 2010; Rizescu & Tileaga, 2016). However, these changes come with their benefits and drawbacks, and need to be governed to have a smooth transition to the cloud.

2.2 IT governance with a focus on change management

IT governance is a subset of corporate governance (Marnewick & Labuschagne, 2011), which is a combination of mechanisms, processes and practices that direct and control an organisation (Cheng & Gong, 2012; IT Governance Institute, 2019b). IT governance ensures that the organisation's IT aligns, sustains and extends the corporate strategies (Marnewick & Labuschagne, 2011).

The implementation of IT governance to oversee changes due to cloud computing comes with various benefits (Gheorghe, 2011; Selig, 2018). IT governance ensures there are controls in place that address identified risks. These controls are usually based on different industry standards and implemented within the organisation. An IT governance framework ensures that policies and procedures are as a form of guidance to standardise IT processes. IT governance also ensures that there is an adherence to legal and regulatory requirements. Governance frameworks like ITIL and COBIT make it easier to determine the operating effectiveness of different systems implemented within an organisation.

Implementing IT governance to govern changes such as cloud computing transitioning, comes with its own set of challenges (Cheng & Gong, 2012; Selig, 2018). Implementing IT governance processes can be very costly; thus, it is crucial to ensure the correct size is applied. Implementing IT governance processes does not necessarily result in tangible end products, so getting stakeholders to buy into the idea of implementing this could be tricky. Project sponsors and process owners could have different expectations when implementing IT governance, thus it could result in failure. Integrating the existing standard could be a challenge if the organisation wants to optimise the adopted governance framework. An organisation should have a mature information management plan to implement successful IT governance.

https://doi.org/10.18489/sacj.v35i2.17441

Within COBIT's Build, Acquire and Implement (BAI) domain, management objective BAI05 focuses explicitly on managing organisational change. The purpose of this management objective is to maximise the likelihood of successfully implementing sustainable enterprise-wide organisational change quickly and with reduced risk (IT Governance Institute, 2019a). This management objective covers the entire life cycle of the change and all affected stakeholders in the organisation as well as IT. There are seven management practices that support the change management objective (Abu-Musa, 2009; IT Governance Institute, 2019b):

1. **Establish the desire to change** This is to fully comprehend the extent and possible consequences of the desired change. Prior to a change being implemented, organisations must have a desire to transition to the cloud. For an organisation to transition to the cloud, all involved stakeholders must be keen and ready to change. However, to be successfully implemented, there must be some form of drive to influence stakeholders to participate in the transition to the cloud.

2. **Form an effective implementation team** Create an implementation team with appropriate team members – this will ensure there are measurable common goals that enable a smooth transition to the cloud.

3. **Communicate the desired vision** Effectively communicate the desired vision to transition to the cloud in a manner that will be understood by everyone involved.

4. **Empower role players and identify short-term wins** Ensure that accountability is enabled for those with roles in the transition to cloud computing. Crucial short-term wins that enable cloud transitioning should be communicated.

5. **Enable operation and use** Establish technical, operational and usage aspects of cloud computing to enable all parties to exercise their responsibilities.

6. **Embed new approaches** Instil a new outlook by monitoring the cloud transition and determining the adequacy of the use and operation plan, and ensuring there is continuous awareness.

7. **Sustain changes** Encourage and endure cloud transitions by ensuring staff members are trained, continuous communication is maintained, top leadership is committed, and adoption is tracked and monitored.

Furthermore, the BAI05 management objective addresses aspects of managing changes in an organisation, within the context of introducing new technologies, which in this case, would be referring to cloud computing. The change management objective within COBIT, ensures that changes are effectively implemented whilst managing all the risks that could arise (IT Governance Institute, 2019b). It also ensures that all the involved parties, including individuals in business and IT, are fully supportive of the vision and understand the risks associated with the change (IT Governance Institute, 2019b).

https://doi.org/10.18489/sacj.v35i2.17441

3 RESEARCH METHODOLOGY

To determine the appropriate research methodology, firstly, an appropriate research paradigm had to be determined. After careful consideration, a quantitative research approach was found to be appropriate (Balnaves & Caputi, 2001). Secondly, an appropriate research strategy had to be determined. The survey research strategy was found to be appropriate, as it gave a holistic view of the phenomenon, and is associated with quantitative research. This research made use of a closed-ended questionnaire to obtain a meaningful number of responses in a cost-effective manner. The questionnaire consisted of three parts. The first part focused on biographical information. The second part focused on cloud computing – on the benefits of cloud computing as well as the deployment models. The third part focused on the IT governance change management processes. Although there are drawbacks to using a questionnaire, the benefits outweigh the drawbacks in this research, and some of these benefits include: (i) data is collected directly from the respondent, (ii) data can be collected in a quantitative or qualitative form, (iii) it provides a holistic view, thus can be generalised and (iv) data can be collected within a short period at a low cost.

Furthermore, an appropriate timeframe had to be determined. After careful consideration, the study needed to be conducted at a single point in time using various individuals, thus, the cross-sectional research time frame was selected. In addition, an appropriate sampling technique had to be determined. A population of IT managers and IT executives within the South African banking sector was identified for this research. Using a stratified sampling technique provides insight to the different groups within the population and ensured accountability of the subgroups (Saunders et al., 2016). However, not all IT managers and executives had adequate insight and knowledge of cloud computing or IT change management to obtain sufficient insights required on these subjects. Therefore, subgroups of IT managers and executives with experience in cloud computing, change management and IT governance were identified. This provided a potential 16 candidates per bank, who could complete the questionnaire to provide insightful data. This resulted in a total of 64 potential candidates from the four banks. A sample size of 56 is sufficient to conduct a successful study (Krejcie & Morgan, 1970).

Lastly, an appropriate method to collect and analyse the collected data had to be determined. A data analysis framework was established, which consisted of five phases: data collection, data preparation, data analysis, interpretation and discussion (Miles et al., 2019; Pesämaa et al., 2021).

Data collection and preparation process were meticulously and systematically performed, ensuring that there was no erroneous capturing of data or introduction of bias in the gathered data. The survey was created using Google Forms. A link was shared with the participants via email and LinkedIn. The research aimed to reach a total of 56 participants, as per the sampling approach. However, the target was exceeded with a total of 59 respondents who opted to participate in the research survey. This enabled the researchers to set up the data collection process in a way that ensured the participants: (i) did not submit blank responses by making sure that all the required fields were completed before they could move to the

next question and (ii) data types were collected as needed i.e., numbers, texts and Boolean variables. Data from Google Forms were exported into SPSS for data interpretation. Results and analysis were also exported from SPSS to Excel. The applications' internal export function was utilised to avoid the manual manipulation of data.

4 DATA ANALYSIS AND DISCUSSION

The goal of this section, in line with the objective of this research, was to analyse, interpret and discuss the data collected for the purposes of assessing the feasibility of using COBIT to adequately manage organisational change when moving to the cloud.

A Cronbach's alpha reliability test was performed using the Statistical Package for the Social Sciences (SPSS) built-in scale functionality. The Cronbach's alpha reliability results for this research were 0.876, and based on the results, this is good, and the data was reliable (Field, 2018). Furthermore, the analysis of the data was performed using Microsoft Excel and its related formulae and analysis tools to gain insights from the gathered data. Lastly, correlation analyses were performed to determine any possible relationship between the different variables.

4.1 Biographical information

The biographical information that was gathered, focused on the participants' level and type of experience in IT governance, the participants' level and type of experience in cloud computing and lastly, the participants' level of experience in the banking industry. The results are depicted in Figure 3, Figure 4 and Figure 5.

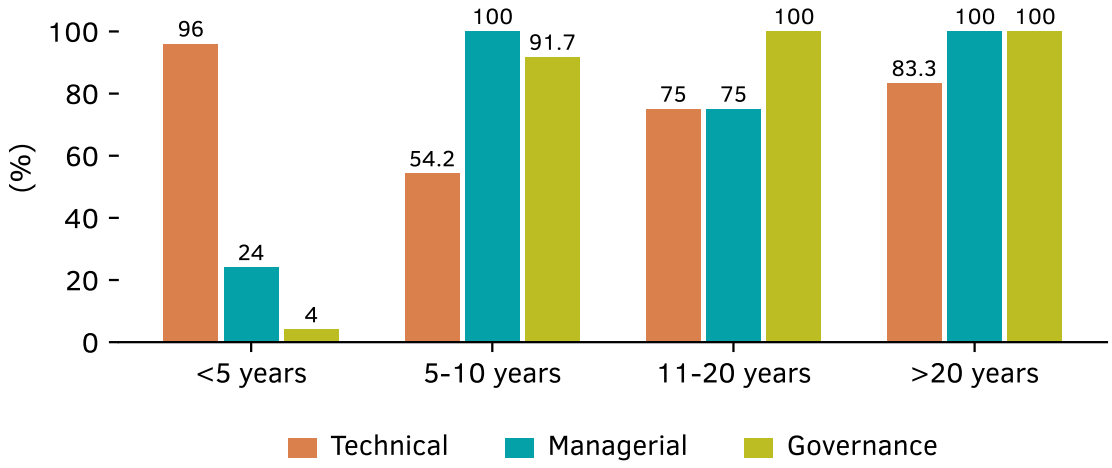


Figure 3: Relationship between the IT governance focus areas and the participants' years of experience.

Figure 3 shows that the participants with less than five years of experience have more technical experience in IT governance than the other two focus areas. Participants with more than five years of experience have more managerial and governance experience in IT governance, than the technical experience focus area. This could imply that the more years of experience the participants have, there is a better chance of them being exposed to more managerial and governance responsibilities. This tends to be the average number years by when most employees become managers or executives.

Figure 4 shows that the participants with less than five years of experience have more technical experience in cloud computing than the other two focus areas. Participants with five to ten years of experience in cloud computing have more managerial and governance experience than the technical experience focus area. This could imply that the more years of experience the participants have, the better chance of them being exposed to managerial and governance responsibilities in cloud computing.

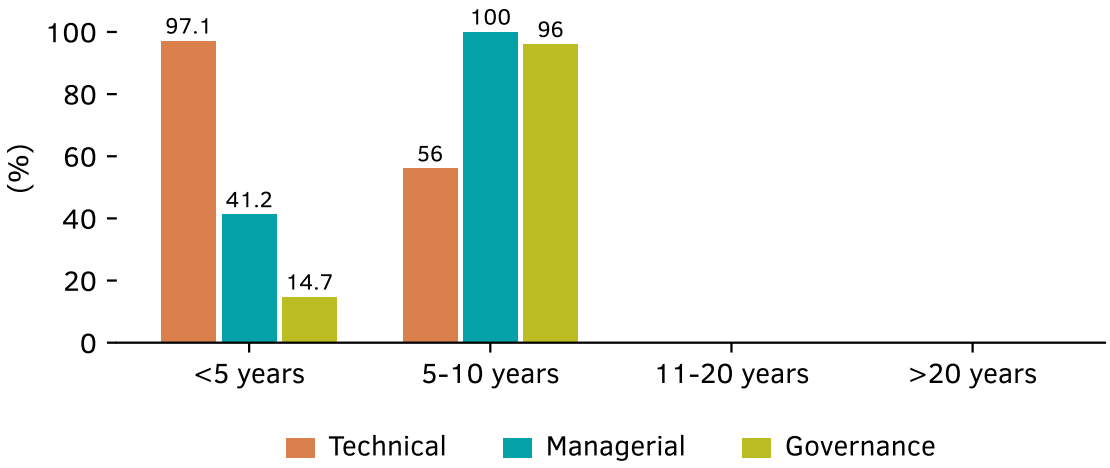


Figure 4: Relationship between the cloud computing focus areas and the participants' years of experience.

Figure 5 shows that out of the 59 participants with experience in the banking industry, 39% (23) have five to 10 years of experience, 35.6% (21) have 11 to 20 years, 15.3% (9) have more than 20 years and 10.2% (6) have less than five years. It also shows that the minority of the participants have less than five years of experience in the banking industry. This reason could be that a manager in a bank needs to have a good understanding of the banking business prior to being considered for this role. Furthermore, this research targeted individuals who were IT managers and IT executives.

https://doi.org/10.18489/sacj.v35i2.17441

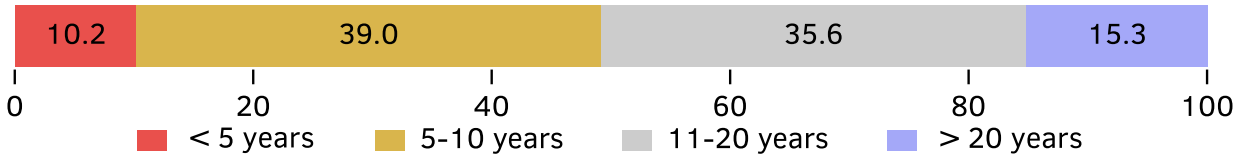


Figure 5: Participants' years of experience in the banking sector.

4.2 Cloud computing

The cloud computing information that was gathered focused on the participants' level of involvement, as well as the success rate of the cloud computing projects and the different cloud project phases in which the participants were involved, the impact of introducing cloud computing in the environment of the participants' organisations, the key drivers to move to the cloud, the cloud service providers and the services the participants' organisations opted to use, and the benefits and drawbacks of moving to the cloud.

The results in Figure 6 showed that all the participants were involved in cloud computing projects. As a result, their input would be in alignment with the objectives of this research. Most (62.7%) were *Often* involved and 25.4% were *always* involved in cloud computing projects.

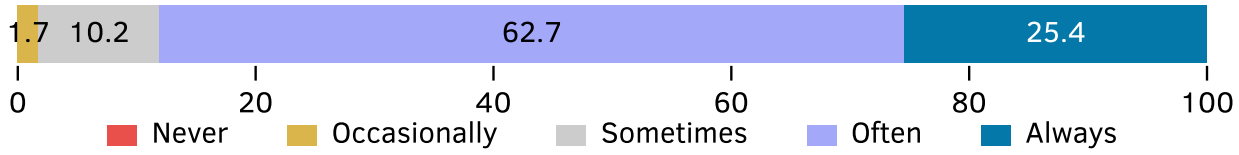


Figure 6: Participants involvement in cloud computing projects (as %).

Based on the participants' involvement in cloud computing projects Figure 7, 54.2% of the respondents said they either agree or strongly agree that the projects were successful. Disturbingly, 44.1% of the respondents provided a neutral response implying that the projects could be perceived as either failures or successes.

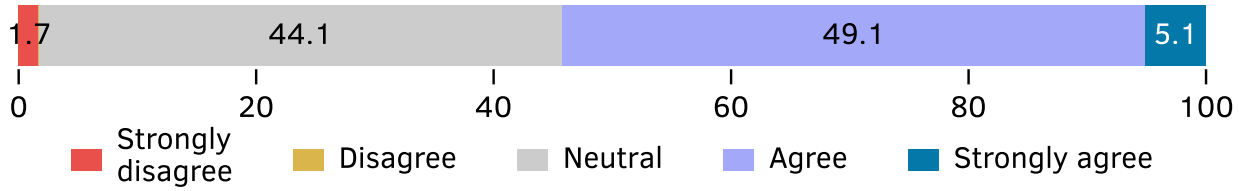


Figure 7: Cloud computing project success rate (participant %).

There is definitely still room for improvement to have successful cloud computing projects.

https://doi.org/10.18489/sacj.v35i2.17441

Furthermore, most participants were involved in the planning, execution, monitoring and reporting phases as seen in Figure 8.

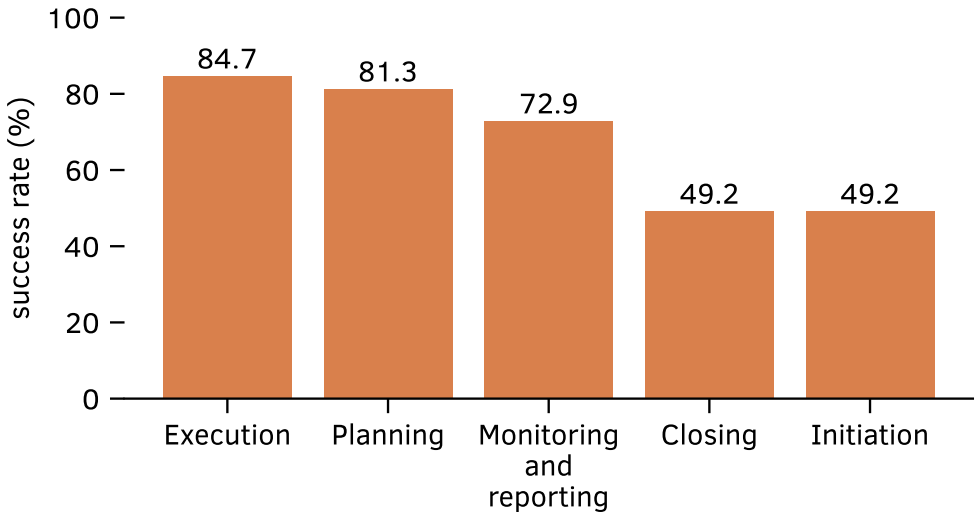


Figure 8: Relationship between the success rates of the phases of cloud computing projects and the participants' views of these.

The results in Figure 9 show that the introduction of cloud computing in the participants' organisations has had a high to severe impact on all the business areas. The biggest impact is on the infrastructure area. This is quite expected as cloud computing does first have an impact on the IT infrastructure. The second most affected area relates to the change associated with the roles and responsibilities when it comes to transitioning to the cloud. The least impacted area is project management.

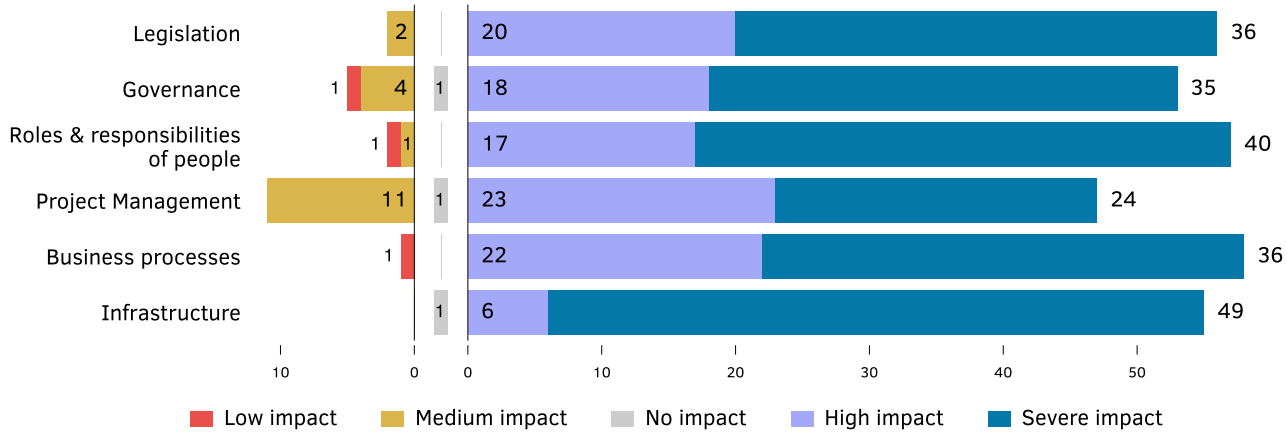


Figure 9: Impact on different areas when transitioning to the cloud.

https://doi.org/10.18489/sacj.v35i2.17441

Transitioning to the cloud is motivated by various reasons. The participants were mainly driven by technological innovation, competition, and growth to move to the cloud as depicted in Figure 10. Respondents could select multiple drivers for transitioning to the cloud.

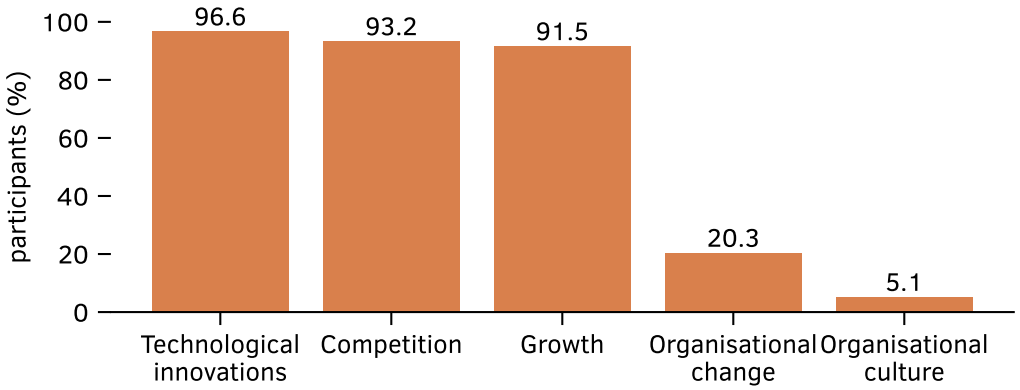


Figure 10: Drivers of the desire to move to the cloud.

The results further showed that although AWS and Microsoft Azure are the leading service provider, SAP and Salesforce are also present in the participants' organisations, as seen in Figure 11, while Google Cloud is not very dominant in the banking sector as would have been expected.

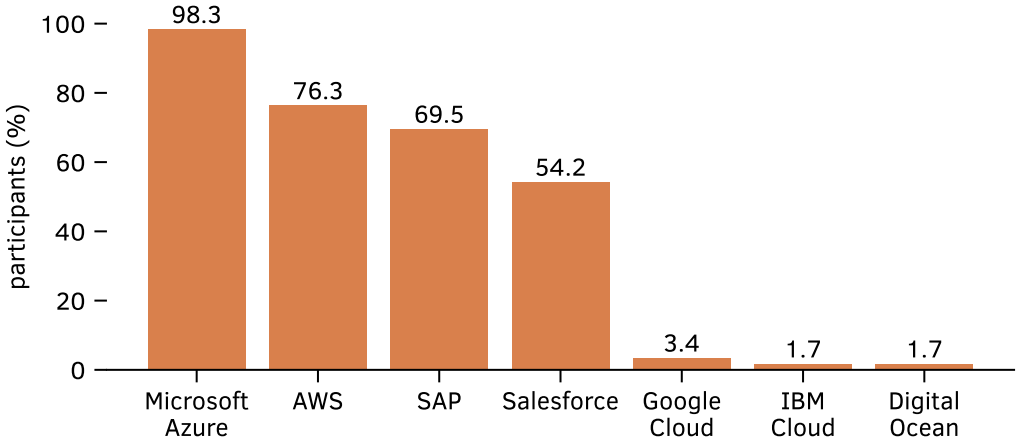


Figure 11: Service providers used by the participants' organisations.

There is also a high use of the private cloud deployment model in the banking sector as seen in Figure 12, which could be due to the sensitivity of the data gathered and used in banks.

https://doi.org/10.18489/sacj.v35i2.17441

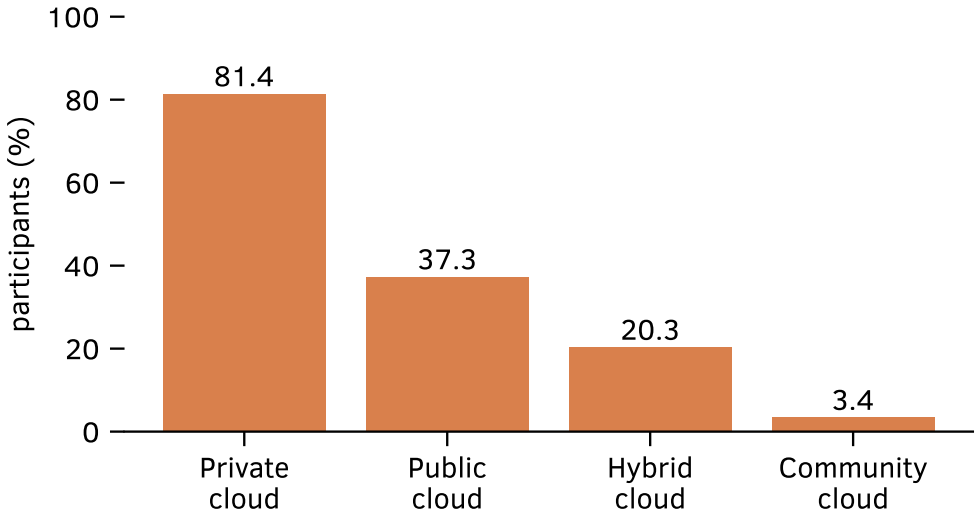


Figure 12: Cloud deployment models used by the banking sector.

4.3 IT governance with a focus on change management

There are management practices that support the change management objective, as per the COBIT framework. Figure 13 shows the participants' responses to the key COBIT framework statements to gather data in relation to their organisations' cloud transitioning. The objective of this gathered data was to determine if this framework would be sufficient to manage cloud transitioning in an organisation. The results in Figure 13 show that the framework would be sufficient. The governance activity that is perceived as the most influential is the establishment of a desire to move to the cloud. This was followed by the establishment of an implementation team. The two least influential activities are the identification of short-term wins and the empowerment of key role players.

Furthermore, the results indicated that there is some correlation between the success of the project and the different COBIT framework activities. A summary of this relationship is depicted in Figure 14.

The correlations strongly suggest that three activities contribute to successful cloud transitioning. The remaining activities do have an impact, but it is not as evident to what extent it contributes to the successful transitioning to the cloud.

Strong correlations

Project success and a desire to change and migrate to the cloud was established This implies that there is a strong correlation between the two variables, meaning that to increase the likelihood of a successful project, a desire to change and migrate to the cloud needs to be established. This means that if there is no desire to change and migrate to the cloud, there is a higher chance that the project will not be successful.

https://doi.org/10.18489/sacj.v35i2.17441

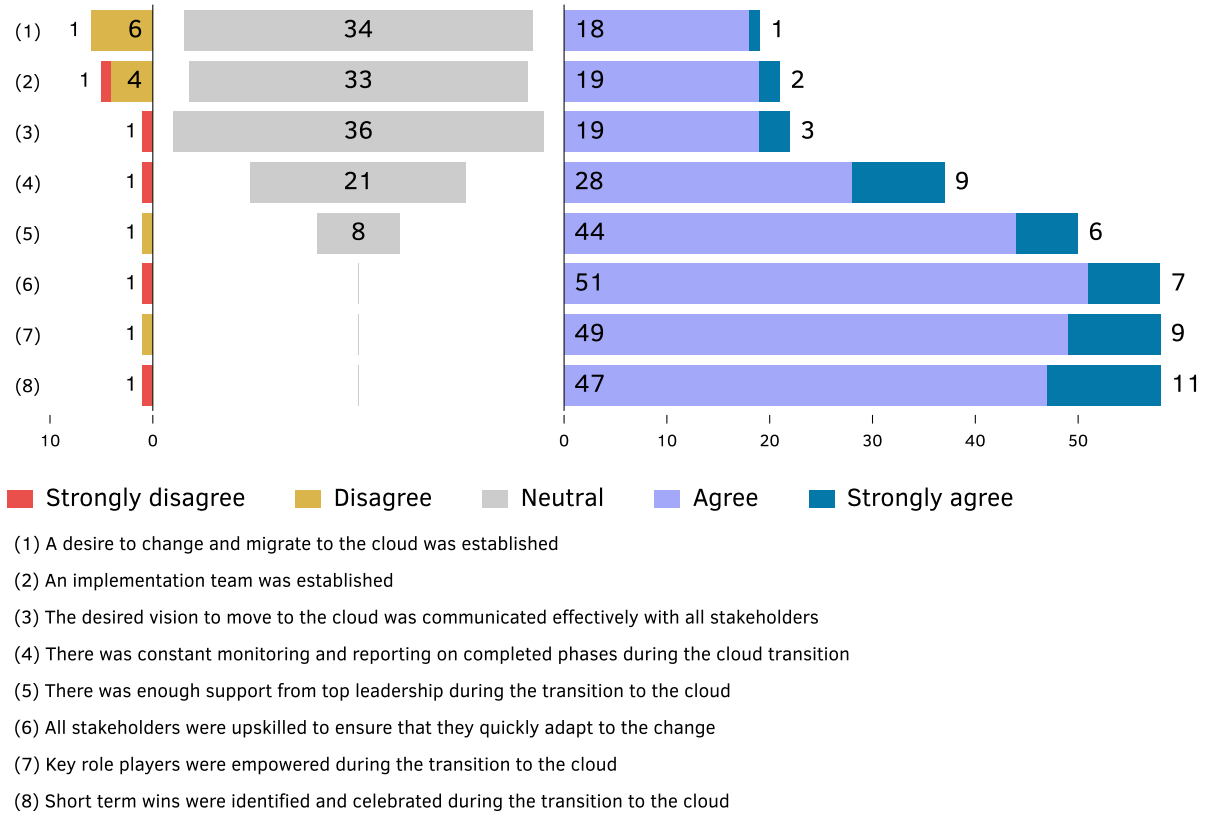


Figure 13: COBIT framework change management activities assisting organisations' move to the cloud.

Project success and an implementation team was established This implies that there is a strong correlation between the two variables, meaning that to increase the likelihood of a successful project, an implementation team needs to be established. This means that if there is no implementation team, there is a high chance that the project will not be successful.

Project success and the desired vision to move to the cloud was communicated effectively with all stakeholders This implies that there is a strong correlation between the two variables, meaning that to increase the likelihood of a successful project, there has to be a desired vision to move to the cloud that is effectively communicated to all stakeholders. If the desired vision is effectively communicated with all stakeholders, they would support this, which ultimately increases the chances of a project being successful.

Moderate correlations

Project success and key role players were empowered during the transition to the cloud This implies that there is a moderate correlation between the two variables, meaning that to

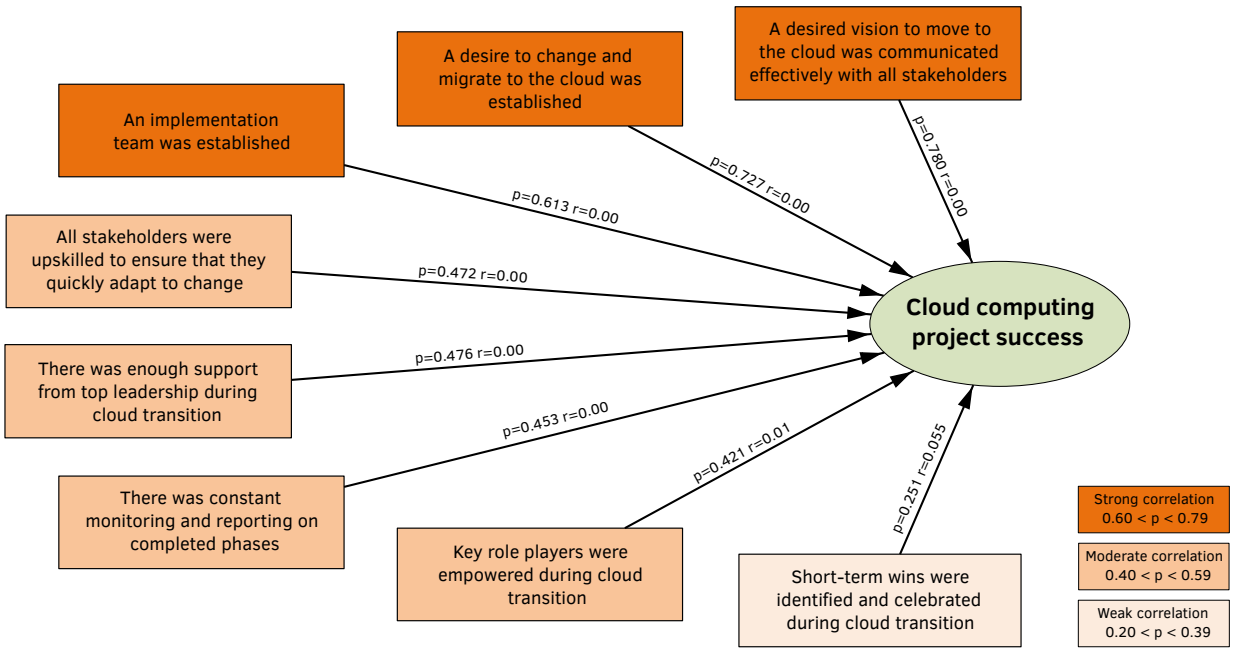


Figure 14: Correlations between cloud computing project success and the different COBIT framework activities.

increase the likelihood of a successful project, the key role players need to be empowered during the transition to the cloud. This could mean that if the key role players are empowered, it could increase team morale, and therefore, result in a successful project.

Project success and all stakeholders were upskilled to ensure that they quickly adapt to the change This implies that there is a moderate correlation between the two variables, suggesting that to increase the likelihood of a successful project, all stakeholders need to be upskilled to ensure that they can quickly adapt to change. This could be due to the acquired knowledge resulting in insightful perspectives from different stakeholders, which could increase the likelihood of a successful project.

Project success and constant monitoring and reporting on completed phases during the cloud transition This implies that there is a moderate correlation between the two variables, meaning that to increase the likelihood of a successful project, there must be constant monitoring and reporting on the completed phases during the cloud transition. This could be due to learnings from previous deliverables resulting in better outcomes of those in future projects.

Project success and enough support from top leadership during the transition to the cloud This implies that there is a moderate correlation between the two variables, meaning that to increase the likelihood of a successful project, there needs to be enough support from

top leadership during the transition to the cloud. This could be due to minimal pushbacks from different stakeholders since the directive comes from top leadership.

5 CONCLUSION

The purpose of this paper was to determine whether change management processes have any influence on the success of cloud transitioning. This was done from the perspective of IT governance and specifically COBIT. The study was conducted in four of the major banks in South Africa.

The results clearly indicate that 50% of the respondents do not believe that their cloud computing transitions were successful. The results indicate that three of the change management practices have a strong positive impact on the success of cloud computing transition. The study did not investigate the presence of these practices. This might be included in future research. Four of the practices have a moderate positive impact on the success of cloud computing transition. The implication is that the change management practices as defined by COBIT, can be used to successfully transition to cloud computing.

The cloud computing transition impacted the infrastructure area the most. This might be because infrastructure is typically what gets moved from on-premises to the cloud. This also has an impact on the roles and responsibilities of the people involved in this transition. What is surprising, is that project management is the least affected area.

The main reasons for moving to the cloud are technological innovations, competition, and growth. This confirms results from literature (Haris & Khan, 2018; Marston et al., 2011; Saini et al., 2019; Singh, 2012).

Although this research study discovered and validated different theories within the broader field of governing cloud transition, there were inherent limitations either known or unknown at the start of the research or revealed while the research was being conducted.

The results presented in this research, as well as the limitations encountered, present opportunities for future research. Some of these future research opportunities include:

(i) Conducting research that will be valid externally to the South African banking sector.

(ii) Considering all stakeholders impacted by cloud transitions and across multiple sectors.

Future research should also investigate the actual importance of the change management practices as well as the application thereof. Another avenue for research is the impact of cloud computing on the organisation and the employees. This is important since the roles and responsibilities were highlighted as an area of concern.

FINAL WORDS

Human beings change as they grow older and in the process of evolving and adapting to new environments, comes learning. To learn something new, one needs to be curious and ask

questions. The curiosity could be due to wanting to test what you already know, wanting to understand the other side of a problem, wanting to establish a reliable guide, wanting to expand your knowledge on a specific concept, wanting to predict, explain and interpret a specific behaviour, and wanting to provide a solution to a problem.

In this research, the identified problem had potential solutions, but with the potential to be improved. Change management processes have some influence on the success of cloud transitioning as identified in the literature and this was empirically validated and confirmed in the data analysis section. There are no shortcuts in conducting research, although through the process, challenges and limitations may be encountered. This does not necessarily mean that the research is lacking, but rather an opportunity for future research.

References

Abu-Musa, A. (2009). Exploring the importance and implementation of COBIT processes in Saudi organizations. *Information Management & Computer Security*, *17*(2), 73–95. https://doi.org/10.1108/09685220910963974

Akar, E., & Mardiyan, S. (2016). Analyzing factors affecting the adoption of cloud computing: A case of Turkey. *KSII Transactions on Internet and Information Systems*, *10*(1). https://doi.org/http://dx.doi.org/10.3837/tiis.2016.01.002

Almishal, A., & Youssef, A. (2014). Cloud service providers: A comparative study. *International Journal of Computer Applications & Information Technology*, *5*(2), 46–52. https://doi.org/http://www.ijcait.com/IJCAIT/52/522.pdf

Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., & Zaharia, M. (2010). A view of cloud computing. *Communications of the ACM*, *53*(4), 50–58. http://doi.acm.org/10.1145/1721654.1721672

Balnaves, M., & Caputi, P. (2001). *Introduction to quantitative research methods - an investigative approach*. Sage Publishers. http://www.uk.sagepub.com/books/Book210544?

Borgman, H., Bahli, B., Heier, H., & Schewski, F. (2013, January). Cloudrise: Exploring cloud computing adoption and governance with the TOE framework. https://doi.org/10.1109/HICSS.2013.132

Cheng, X., & Gong, Y. (2012). A study of the application of information technology in corporate governance of Li Ning Co., Ltd. *2012 Fourth International Conference on Computational and Information Sciences*, 750–753. https://doi.org/10.1109/ICCIS.2012.48

Conway, G., & Curry, E. (2012). Managing cloud computing – A life cycle approach. *2nd International Conference on Cloud Computing and Services Science (CLOSER 2012)*, 198–207. https://doi.org/https://www.edwardcurry.org/publications/Conway_IVILifecycle.pdf

Da Veiga, A. (2018). An approach to information security culture change combining ADKAR and the ISCA questionnaire to aid transition to the desired culture. *Information & Computer Security*, *26*(5), 584–612. https://doi.org/10.1108/ICS-08-2017-0056

Erasmus, W., & Marnewick, C. (2021). An IT governance framework for IS portfolio management. *International Journal of Managing Projects in Business*, *14*(3), 721–742. https://doi.org/10.1108/IJMPB-04-2020-0110

Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications. https://uk.sagepub.com/en-gb/afr/discovering-statistics-using-ibm-spss-statistics/book257672

Gacenga, F., Cater-Steel, A., & Toleman, M. (2010). An international analysis of IT service management benefits and performance measurement. *Journal of Global Information Technology Management*, *13*(4), 28–63. https://doi.org/10.1080/1097198X.2010.10856525

Gheorghe, M. (2011). Risk management in IT governance framework. *Economia Seria Management, 14*(2). http://www.management.ase.ro/reveconomia/2011-2/27.pdf

Gimmon, E., & Benjamin, E. (2014). Internal and external drivers of radical strategic changes in high technology new ventures. *ACRN Journal of Finance and Risk Perspectives*, *3*(3), 35–52. http://www.acrn-journals.eu/resources/jfrp201403c.pdf

Haris, M., & Khan, R. Z. (2018). A systematic review on cloud computing. *International Journal of Computer Sciences and Engineering*, *6*(11), 632–639. https://doi.org/10.26438/ijcse/v6i11.632639

Hentschel, R., Bley, K., & Schön, H. (2021). Shifting micro-enterprises into the cloud: Guidelines for cloud service providers. *Hawaii International Conference on System Sciences (HICSS)*. https://hdl.handle.net/10125/71192

Hornstein, H. A. (2015). The integration of project management and organizational change management is now a necessity. *International Journal of Project Management*, *33*(2), 291–298. https://doi.org/http://dx.doi.org/10.1016/j.ijproman.2014.08.005

Institute of Directors Southern Africa. (2016). *King IV report on corporate governance* (Report). Institute of Directors Southern Africa. https://c.ymcdn.com/sites/iodsa.site-ym.com/resource/collection/684B68A7-B768-465C-8214-E3A007F15A5A/IoDSA_King_IV_Report_-_WebVersion.pdf

IT Governance Institute. (2019a). *CobiT 2019: Governance and management objectives*. ITGI. https://www.isaca.org/resources/cobit

IT Governance Institute. (2019b). *CobiT 2019: Introduction and methodology*. ITGI. https://www.isaca.org/resources/cobit

Jayeola, O., Sidek, S., Sanyal, S., Hasan, M. M., Singh, A. P., & Hasan, S. I. (2022). The nexus between top management support on change management, cloud ERP implementation, and performance of SMEs. *Academic Journal of Interdisciplinary Studies*, *11*(3), 293–309. https://doi.org/10.36941/ajis-2022-0084

Kotter, J. P. (1995). Leading change: Why transformation efforts fail. *Harvard Business Review*, *73*(2), 59–67. https://hbr.org/1995/05/leading-change-why-transformation-efforts-fail-2

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement, 30*(3), 607–610. https://doi.org/10.1177/001316447003000308

Leavitt, N. (2009). Is cloud computing really ready for prime time? *Computer*, *42*(1). https://doi.org/10.1109/MC.2009.20

Li, X., Zhou, L., Shi, Y., & Guo, Y. (2010). A trusted computing environment model in cloud architecture. *2010 International Conference on Machine Learning and Cybernetics*, *6*, 2843–2848. https://doi.org/10.1109/ICMLC.2010.5580769

Marnewick, C., & Labuschagne, L. (2011). An investigation into the governance of information technology projects in south africa. *International Journal of Project Management*, *29*(6), 661–670. https://doi.org/10.1016/j.ijproman.2010.07.004

Marnewick, C., & Langerman, J. (2021). DevOps and organizational performance: The fallacy of chasing maturity. *IEEE Software*, *38*(5), 48–55. https://doi.org/10.1109/MS.2020.3023298

Marrone, M., & Kolbe, L. (2011). Impact of IT service management frameworks on the IT organization. *Business & Information Systems Engineering*, *3*(1), 5–18. https://doi.org/10.1007/s12599-010-0141-5

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing – The business perspective. *Decision Support Systems*, *51*(1), 176–189. https://doi.org/10.1016/j.dss.2010.12.006

Mell, P., & Grance, T. (2011, September). *The NIST definition of cloud computing* (Rep.). National Institute of Standards and Technology. https://doi.org/10.6028/NIST.SP.800-145

Miles, M. B., Huberman, A. M., & Saldana, J. (2019). *Qualitative data analysis – A methods sourcebook*. SAGE Publications, Inc.

Narula, S., Jain, A., & Prachi, Y. (2015). Cloud computing security: Amazon web service. *2015 Fifth International Conference on Advanced Computing & Communication Technologies*, 501–505. https://doi.org/10.1109/ACCT.2015.20

Pesämaa, O., Zwikael, O., Hair, J. F., & Huemann, M. (2021). Publishing quantitative papers with rigor and transparency. *International Journal of Project Management*, *39*(3), 217–222. https://doi.org/10.1016/j.ijproman.2021.03.001

Rastogi, G., & Sushil, R. (2015). Cloud computing implementation: Key issues and solutions. *2015 2nd International Conference on Computing for Sustainable Global Development (INDIACom)*, 320–324. https://ieeexplore.ieee.org/abstract/document/7100266

Ratana, S. O. M., Raksmey, C., & Danut, D. (2020). Conceptualizing a framework: A critical review of the development of change management theories. *Studies in Business & Economics*, *15*(2), 205–214. https://doi.org/10.2478/sbe-2020-0035

Rebollo, O., Mellado, D., Fernández-Medina, E., & Mouratidis, H. (2015). Empirical evaluation of a cloud computing information security governance framework. *Information and Software Technology*, *58*, 44–57. http://dx.doi.org/10.1016/j.infsof.2014.10.003

Rizescu, A., & Tileaga, C. (2016). Factors influencing continuous organisational change. *Journal of Defense Resources Management*, *7*(2), 139–144. https://www.ceeol.com/search/article-detail?id=472955

Saini, H., Upadhyaya, A., & Khandelwal, M. K. (2019). Benefits of cloud computing for business enterprises: A review. *Proceedings of International Conference on Advancements in Computing & Management (ICACM)*. http://dx.doi.org/10.2139/ssrn.3463631

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7th ed.). Pearson Education.

Selig, G. J. (2018). IT governance – An integrated framework and roadmap: How to plan, deploy and sustain for competitive advantage. *2018 Portland International Conference on Management of Engineering and Technology (PICMET)*, 1–15. https://doi.org/10.23919/PICMET.2018.8481957

Singh, H. (2012). Cloud computing: An internet based computing. *International Journal of Computers and Technology*, *2*(3), 116–121. https://doi.org/10.24297/ijct.v2i3b.2701

Stein, M., Campitelli, V., & Mezzio, S. (2020). Managing the impact of cloud computing: Certified public accountant. *The CPA Journal*, *90*(6), 20–27. https://www.proquest.com/docview/2420174077?accountid=13425

Subashini, S., & Kavitha, V. (2011). A survey on security issues in service delivery models of cloud computing. *Journal of Network and Computer Applications*, *34*(1), 1–11. https://doi.org/10.1016/j.jnca.2010.07.006

Tang, K. N. (2019). Change management. In K. N. Tang (Ed.), *Leadership and change management* (pp. 47–55). Springer Singapore. https://doi.org/10.1007/978-981-13-8902-3_5

Thobejane, M., & Marnewick, C. (2020). The effective implementation of cloud computing through project management: Conceptual framework. *Journal of Contemporary Management*, *17*(2), 416–444. https://doi.org/10.35683/jcm20079.82

Tshabalala, M. M., & Marnewick, C. (2021). Agile as an enabler towards innovation-based organisational transformations. *SA Journal of Information Management*, *23*(1), 1–10. https://doi.org/10.4102/sajim.v23i1.1309

Youssef, A. (2014). Exploring cloud computing services and applications. *Journal of Emerging Trends in Computing and Information Sciences*, *3*(6), 838–847. https://www.oalib.com/paper/2047543

SACJ 35(2) December 2023
Research Article

Virtual learner experience (VLX): A new dimension of virtual reality environments for the assessment of knowledge transfer

Johanna Steynberg, Judy van Biljon, Colin Pilkington
University of South Africa, South Africa

ABSTRACT
Science educators need tools to assess to what extent learners' knowledge can be transferred to novel real-world situations. Virtual reality learning environments (VRLEs) offer the possibility of creating authentic tools where situated learning and assessment can take place, but there is a lack of evidence-based guidelines to inform the design and development of the VRLEs focussing on the user, that is the learner experience, especially for secondary schools. Drawing on theoretical premises and guidelines from user experience, usability, and technologically enabled assessment literature, we designed, developed, evaluated, and refined a VRLE prototype for the authentic assessment of knowledge transfer in the secondary school science classroom as guided by the design science research approach. Lessons learnt from the implementation and iterative evaluation of the prototype are presented as a set of literature-based, empirically validated guidelines to support and guide educational designers and developers to create VRLEs focused on supporting the learner experience. The contribution of this study is a VRLE design model with the learner at its core, the definition of VLX to include learner-specific aspects of immersive environments, and guidelines for the development of an effective and efficient virtual reality environment for the assessment of knowledge transfer in science education.

Keywords Augmented and virtual reality; Human-computer interface; 21st-century abilities; Learner experience; Virtual reality learning environments

Categories • **Human-centred computing** ~ **Human computer interaction (HCI), Interaction paradigms, Virtual reality**

Email
Johanna Steynberg – hsteynberg@bluebridgeone.com (CORRESPONDING),
Judy van Biljon – vbiljja@unisa.ac.za,
Colin Pilkington – colinpilkington@gmail.com

Article history
Received: 30 April 2022
Accepted: 7 August 2023
Online: 14 December 2023

1 INTRODUCTION

In January 2020, the World Economic Forum (WEF) stated that the fourth industrial revolution would create the demand for millions of new jobs in completely new occupations over the next few years, due to advances in technologies such as data science and artificial intelligence (World Economic Forum, 2020). The COVID-19 pandemic has accelerated all predictions relating to the digitisation of society (Alakrash & Razak, 2022; Amankwah-Amoah et al.,

Steynberg, J., van Biljon, J., and Pilkington, C. (2023). Virtual learner experience (VLX): A new dimension of virtual reality environments for the assessment of knowledge transfer. *South African Computer Journal* 35(2), 50–77. https://doi.org/10.18489/sacj.v35i2.17442

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

2021). Situations that learners will encounter in their professional lives will vary from having minimal similarity to previous experience to being completely novel. To complicate matters, each person's experience of a situation or problem is unique, and the work environment is constantly changing at an ever-increasing pace (Erebak & Turgut, 2021; Heng & McColl, 2021; Steiber, 2014; Zawacki-Richter & Latchem, 2018). This means that education has to empower learners to use relevant information and recognise situational conditions under which previously mastered skills and knowledge could be applied at a faster pace than ever before and to do this flexibly in these new situations that they have not previously experienced (Çakiroğlu & Gökoğlu, 2019a; Falloon, 2019; Spector et al., 2016).

In secondary school science education, learners need to acquire and develop science skills that are not specific to a domain or situational context but which should transfer through deeper learning to complex, real-life situations that may be predominantly unknown in a learner's daily life (Andrews, 2002; Bogusevschi et al., 2020; Jiang et al., 2015; Spector et al., 2016). For science educators, assessment is crucial for determining the level of transfer of science skills and knowledge across diverse domains and instructional contexts to ensure the successful application of skill and knowledge in novel situations (Çakiroğlu & Gökoğlu, 2019a; Jiang et al., 2015; McHaney et al., 2018). Therefore, science educators need assessment tools that allow for the measurement of knowledge acquired and the level of cognitive or physical skills gained through learners' performance in authentic tasks (Bogusevschi et al., 2020; Novak et al., 2005; Shavelson et al., 1991). Authentic tasks are those that closely represent tasks a learner could encounter in the real world that are believable, challenging, and meaningful with open-ended solutions (Sokhanvar et al., 2021).

Various studies have provided evidence that technology-enabled assessments can support problem-solving and skill development as computers and multimedia technology can provide the complex contexts that constitute realistic situations with tasks similar to those learners would be performing in real-world contexts (Herrington et al., 2013; Kennedy-Clark & Wheeler, 2014; Mikropoulos & Natsis, 2011; Özgen et al., 2019; Pellegrino, 2010; Rosen, 2014; Schott & Marshall, 2018; Spector et al., 2016). Such computer-generated simulation platforms can be used to create authentic virtual spaces that provide safe and effective environments where situated learning, as well as assessment, can take place (Bosman et al., 2021; Çakiroğlu & Gökoğlu, 2019a; Crosier et al., 2002; Idrissi et al., 2017; Kavanagh et al., 2017; Vos, 2015; Zuiker, 2016).

Virtual reality (VR) is the simulation of an environment set up in a synthetic space that embeds a human as a part of the computer system (Craig et al., 2009; Donath & Regenbrecht, 1995; Özgen et al., 2019; Penichet et al., 2013; Portman et al., 2015; Zhou et al., 2018). Abstract concepts and unobservable phenomena, such as magnetic fields, can be visualised in virtual reality in a novel way, supporting learning and assessment through interactivity and personal experience (Bogusevschi et al., 2020; Craig et al., 2009; Crosier et al., 2002; Schott & Marshall, 2018). This enables learners to construct their own knowledge and synthesise it with their existing conceptual frameworks (Madathil et al., 2017; Makhkamova et al., 2020).

Virtual reality learning environments (VRLE's) have the potential to provide such authentic

assessment environments but there are numerous challenges to creating these VR assessment tools. The tension between the opportunities provided by VRLEs and the lack of guidance on designing VRLEs formed the rationale for this study. There are considerable design and implementation challenges when developing an effective VRLE efficiently (Górski et al., 2016; Liu et al., 2016; Zhou et al., 2018). Despite a number of studies providing evidence of the value of VRLEs in education (Concannon et al., 2020; Makransky et al., 2019; Sun et al., 2019), there is a dearth of evidence-based guidelines to support designers and developers, especially in the secondary school environment. This study addressed this research gap by investigating the question: *'Which user experience design aspects of a virtual reality environment are the most critical for the assessment of knowledge transfer in science education?'* Notably, the application context is the secondary school environment.

In 2020, the COVID-19 pandemic affected education in an unprecedented manner. Attempts to continue offering education to 1.7 billion affected learners, in the face of the strict lockdown conditions prevalent in many countries, resulted in a shift to online classrooms (UNESCO, 2020) with the net effect on education being to accelerate the digital transformation of instruction delivery (Adedoyin & Soykan, 2020; Alakrash & Razak, 2022). Successful online instruction delivery requires effective e-assessments to include not only digital versions of closed questions but also more sophisticated tasks and skill-based or competency-based assessments (Joint Information Systems Committee, 2010; Spector et al., 2016; Tinoca et al., 2014). As a result of the pandemic, the shift in education and assessment towards improved technology-enabled environments became crucial to ensure continued quality education and assessment for learners all over the world (Adedoyin & Soykan, 2020; Alakrash & Razak, 2022; Amankwah-Amoah et al., 2021; UNESCO, 2020). Considering these developments, virtual reality classrooms, including virtual assessments, once considered an unaffordable luxury, may become a necessity as priorities adjust to the new reality. Several researchers have proposed design models for VRLEs (see section 2), but the majority of these models do not explicitly consider the unique characteristics of immersive environments, specifically in terms of the context of user experience (UX) design (Akcayir & Epp, 2020). In the light of the global digitisation of education, which was hastened by the influence of the COVID-19 pandemic, the urgency of research addressing the lack of guidance on implementing VR in an educational context is compelling. The research approach and method of this study is explained in section 2, and section 3 describes the evaluation of the prototype and the results of the findings. Section 4 explains the findings and contributions of this study. Section 5 contextualises the results and the paper concludes in section 6.

2 METHODOLOGY

This study focused on constructing guidelines based on a conceptual model for the design and development of an effective and efficient VRLE for the authentic assessment of the transfer of skills and knowledge in the secondary school science classroom. Drawing on theoretical premises from the user experience, usability, and technologically enabled assessment liter-

ature, the research was guided by the design science research (DSR) approach. A practical artefact in the form of a VRLE was developed, directed by the guidelines identified from literature summarised in Table 1 and the initial conceptual model shown in Figure 1.

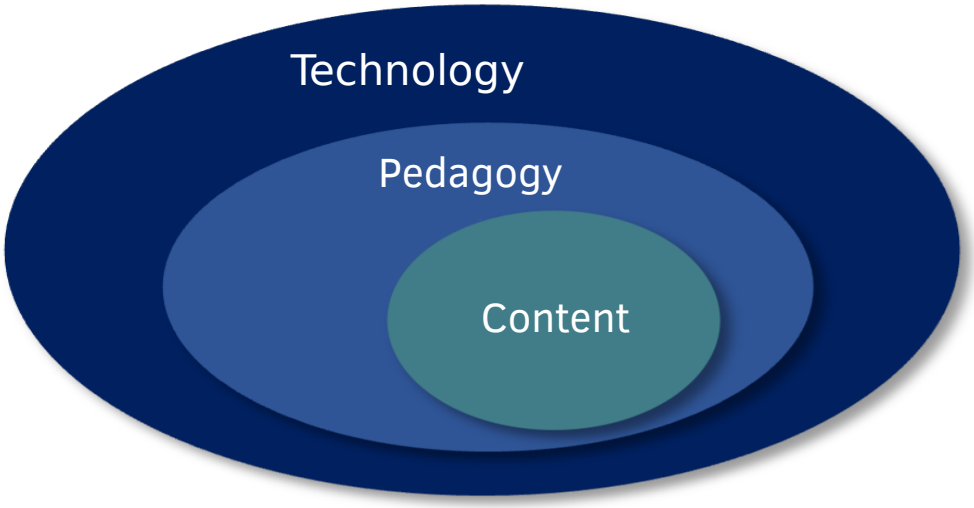


Figure 1: The synergy of a VRLE

The lessons learned during the first iteration of the study were published in 2020 (Steynberg et al., 2020). This paper builds on the findings of the previous publication (as in Table 1) and additionally reports on the findings from the evaluation of the artefact obtained in Phase 2. The previous contribution is extended by this paper's focus on the virtual learner experience (VLX) as an extended view of UX.

Following DSR's iterative process, an artefact was developed and evaluated, focusing on the user experience when using the artefact. Notably, we consider usability as a subset of UX as advocated by Väätäjä et al. (2009). We employed the usability metrics of effectiveness, efficiency, and user satisfaction as core constructs in designing the evaluation, while acknowledging that UX evaluation extends beyond those constructs (Albert & Tullis, 2013). The design, development, and evaluation of the artefact took place over two iterations – iteration one started with a design and specification step, whereafter the development and implementation of Artefact One took place, and the evaluation of Artefact One followed. The results of the first evaluation guided the changes in the second iteration, leading to the modification of the Artefact One and resulted in Artefact Two. All the responses obtained in the evaluation interviews, the observations of users interacting with the VRLE and cost journals, and data from the stealth assessments, were analysed and synthesised as described in Section 3. From these findings, the conceptual model was refined, and guidelines were subsequently constructed, incorporating appropriate suggestions and proposals gleaned from previous published literature.

https://doi.org/10.18489/sacj.v35i2.17442

Table 1: A summary of guidelines identified from literature[a], with lessons learned by the authors

Guidelines	Concept	Lessons learned
Pedagogy Liu et al. (2016) Chen (2006) Clarebout and Elen (2007) Farra et al. (2016) Jeffries (2005) Minocha and Reeves (2010) Parong and Mayer (2018) Ritz and Buss (2016) Schroeder (2016) Vergara et al. (2017)	- Create an authentic environment	- There are very few 3D science assets available to create an authentic environment.
	- Implement visualised content	- Considerable time was needed to design novel visualisations.
	- Pedagogical agents	- Voices using text to speech can be added.
	- Learner as actor	- The learner is not a separate entity but now becomes part of the simulation as he or she interacts with the environment.
	- Storyboards	- Learning material should be divided into chunks.
Content Chen (2006) Minocha and Reeves (2010) Ritz and Buss (2016) Vergara et al. (2017) Desurvire and Kreminski (2018) Minocha and Hardy (2016) Serafin et al. (2016) Snowdon and Oikonomou (2018)	- Realistic learning spaces with real-world metaphors	- Collisions between objects and collision spaces are hard to control and needs extra attention.
		- The learner must engage with the problem manipulation space.
	- Personal space must be respected	- Put restrictions into scenes to protect the learner from harmful areas.
	- Side effects must be mitigated	- Movement that does not originate from the learner can cause vertigo and nausea.
	- Use simple locomotion mechanics to move around	- Do not use hand controllers to turn, only to move forward and backward.
	- Wayfinding via maps, paths or visual clues	- Include visual clues such as blinking shapes.
Technology Mikropoulos and Natsis (2011) Górski et al. (2016) Liu et al. (2016) Chen (2006) Vergara et al. (2017) Bevilacque (2013) Bourg and Seemann (2004)	- Consider purpose, level of immersion and realism, the audience and the cost when selecting hardware and software	- There is a significant trade-off between monetary and time costs versus levels of immersion, realism and interaction.
	- Use a finite-state machine to implement interactive content	- The interactive nature of a learning environment makes sequential programming less efficient.

[a]Steynberg et al. (2020)

2.1 Design and development

Mahdi et al. (2018) and Zhou et al. (2018) concur that VRLE design is a complex activity, integrating technical difficulties from the nature of VRLEs with cognitive aspects, such as content definition and task appropriation. Therefore, they propose that VRLE design and development should combine three different areas – content, pedagogy, and technology.

In a VRLE, these three areas form new interrelationships that cause the three parts to fuse to form a new synergy rather than existing in isolation. This synergy is not simply a sum of the parts – the interaction between and within the parts gives rise to a new integrated environment. Initially, we visualised this as an onion diagram, with content in the centre, pedagogy around it, and technology encapsulating content and pedagogy (Figure 1). The guidelines from different studies were analysed and classified according to this new, integrated environment. When the artefact was designed and developed in Phase 1 of our study, this three-part environment evolved into a conceptual model that was closely followed.

As guided by the conceptual framework, the design of the first layer started with the core of the onion diagram – the definition of the content of the VRLE, namely, the problem, objectives, content, and audience. The problem that this artefact addressed was the assessment of a learner's scientific knowledge and skill transfer to a new situation, focusing on magnetism and electromagnetism. The audience for the VRLE included secondary-school learners who are fluent in English. In 2020, this meant that it included learners who were born between 2002 and 2006. These learners are part of Generation Z, that is, people born after 1995 and before 2013 (Bilonozhko & Syzenko, 2020). The content of the artefact was designed with the characteristics of this audience in mind. By using a dystopian or post-apocalyptic setting in this study, the specific learner group connected and engaged with the theme as was seen by comments such as:

> *"It felt post-apocalyptic like in a movie. It was very cool, I really enjoyed it. It was very easy and an interesting way to learn."* [L3]

Guided by the application context, the levels of immersion and realism were considered, the level of interaction was specified, and the entry point and navigation methods were decided.

Having defined the content, we moved to the next layer of our conceptual model, namely, the design of the pedagogy. The learning scenarios were identified, the levels of differentiation were determined, and the instructional support and scaffolding were described. In the outer layer, that is, technology, the hardware and software to be used were determined, while negative effects such as motion sickness were considered, and the learner's personal space was respected throughout the development. Integrating the designs and suggestions from the three layers of the conceptual model, namely, content, pedagogy, and technology, a detailed design of the VRLE was drafted as a storyboard.

The storyboard includes each scene in the environment, the objectives, details of the scene, action and challenges in the scene, cues, and interactions, what learner response can be expected, change of scene, or redirection away from the scene after a learner's action. The detail of one of the tutorial scenes is shown in Figure 2.

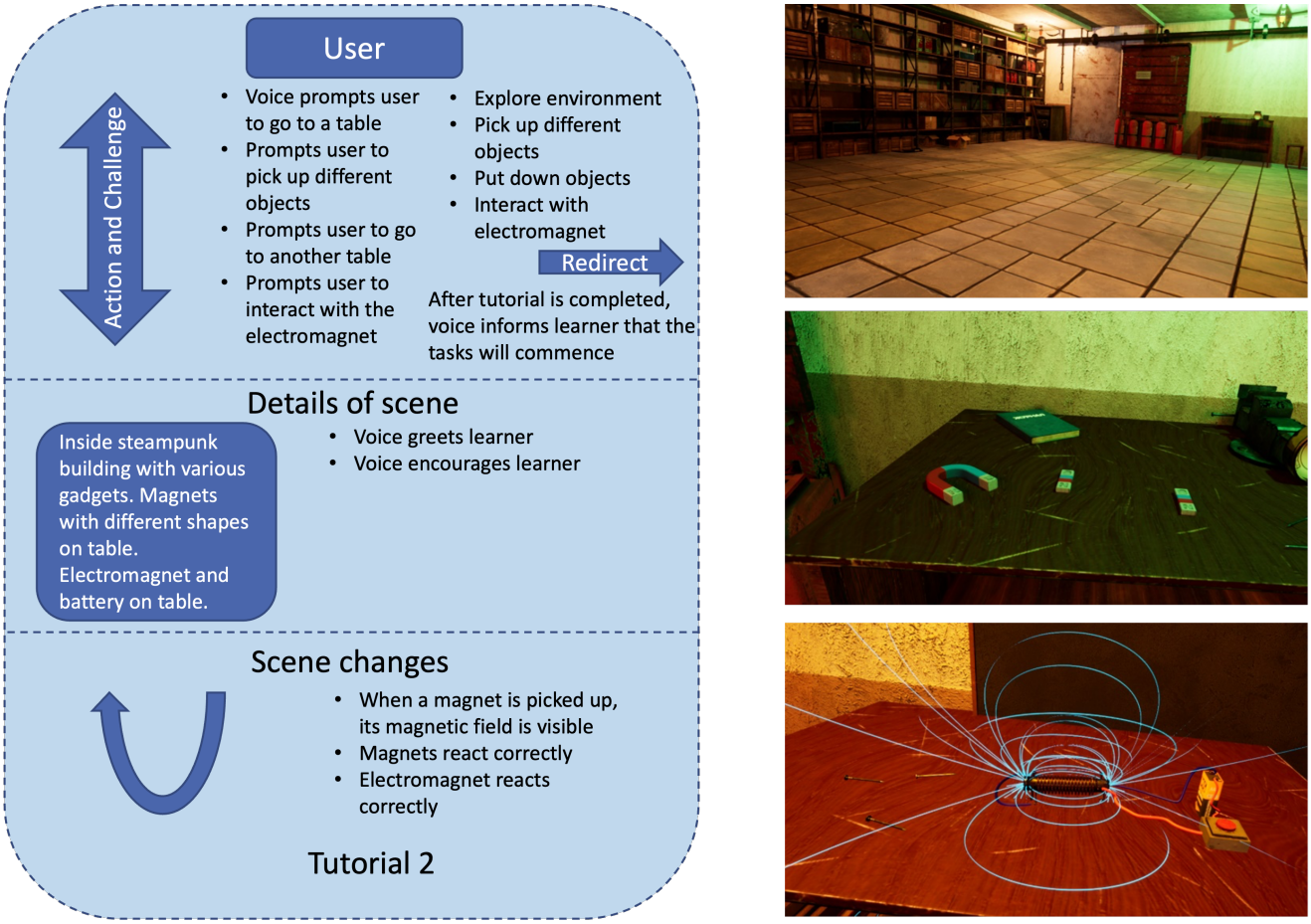


Figure 2: A scene from the VRLE: Tutorial 2

The hardware used in the design and evaluation of the prototype included a desktop computer running Windows 10 with an Intel i7 chip, an NVIDIA GeForce RTX 2070 graphics card, and 64 GB RAM. The head-mounted display used was an Oculus Rift with integrated earphones, two motion sensors and two hand controllers. The prototype was exclusively developed in Unreal Engine 4.22.

2.2 Limitations

VR is not recommended for use by children under the age of 13 years (Nemec et al., 2017). Therefore, this study did not include educational material for elementary learners. Furthermore, this study did not investigate the emotional impact of using VR for assessment purposes, and the use of VR platforms for special needs education is beyond the scope of this study.

Artefact Two was tested by a group of 10 secondary-school learners as a convenience sample. Our sample of only 10 learners might seem limiting in terms of generalisation, how-

https://doi.org/10.18489/sacj.v35i2.17442

ever, when investigating usability, a sample of five participants has been found to uncover 80% of the usability issues (Lewis, 1994; Virzi, 1992). It has also been found that severe usability problems are easier to detect with the first few participants (Lewis, 1994). Albert and Tullis (2013) contend that given a small number of tasks or scenarios and one distinct user group, where it is not paramount that all usability issues should be uncovered, a sample size of between five and 10 participants is sufficient. This study investigated a prototype with only two tasks to be performed with the objective of constructing guidelines for the design and the development of a VRLE. Additionally, the target audience of the artefact is secondary-school learners in the science classroom, a fairly homogenous group of teenagers. As noted, 10 participants are accepted as adequate in usability testing, but we acknowledge that UX is broader than usability and includes several qualities that are more subjectively perceived. Therefore, future work to validate this study's contributions with additional user groups or a more heterogeneous sample is advisable.

3 EVALUATION

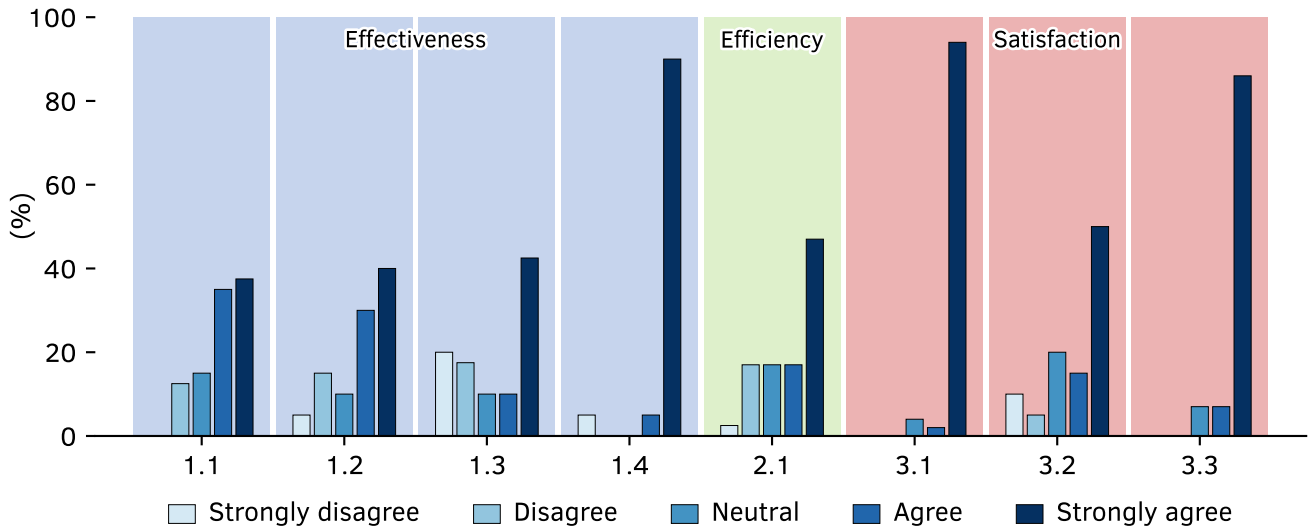
Two evaluation phases were conducted during the development of the VRLE. Phase 1 consisted of an evaluation by three general users and two domain experts. The results and suggested changes fed through to the modification of the VRLE in Phase 2, where the second phase trials were conducted with 10 secondary-school learners. The feedback and results from the second phase evaluation are explored in this paper. Ethics clearance to conduct the trials was granted by Unisa College of Science, Engineering and Technology's Ethics Review Committee with ERC reference number 020/JCS/2019/CSET_SOC.

3.1 Quantitative analysis

Feedback on the learners' experiences was obtained in one-to-one interviews that included Likert-item questionnaires and open-ended questions. For the Likert-item questions, five classes of answers were considered – strongly disagree, disagree, neutral, agree, and strongly agree. The questions captured user perspectives related to the effectiveness, efficiency, and satisfaction experienced when using the VRLE.

The frequency of each scale point grouped per subsection is presented in Figure 3.

Considering effectiveness, there were four questions that addressed effectiveness and 10 participants answered the question. Five of these responses disagreed with the statement, hence, this equates to 12.5%. The other sections were scored in a similar fashion. Physical comfort scored the highest in the evaluations, and it was followed closely by attitude and motivation. Therefore, it can be deduced that satisfaction (3.1, 3.2, and 3.3) was the section where the learners rated their experiences the most positively. Interaction with virtual objects (1.3) and ease of navigation (2.1) scored the lowest in the feedback; thus, it can be concluded that efficiency was the section they rated their experiences least positively.



1.1 Spatial characteristics
1.2 Visual anthenticity
1.3 Interaction with virtual objects
1.4 Consistency of data display
2.1 Ease of navigation and object manipulation
3.1 Physical comfort
3.2 Lack of user frustration
3.3 Attitude and motivation

Figure 3: Frequency chart of each scale point grouped per subsection

The mean and standard deviation were then calculated for each of these subsections and aggregated to find these measures for each section. The count indicates the number of responses per subsection, namely, number of questions × number of participants. The results are displayed in Table 2, supporting the findings from analysing Figure 3, where satisfaction scored the highest with a mean of 4.7083 and a low standard deviation of 0.7788. Similarly, efficiency scored the lowest with a mean of 3.8667 and a standard deviation of 1.2579. This seems to indicate that the learners were satisfied with the experience despite the navigation challenges experienced.

3.2 Thematic analysis

The responses to the open-ended questions from the one-to-one interviews with the learners in the second phase evaluation were analysed and synthesised into themes and sub-themes. This was done through thematic analysis – a method for analysing qualitative data that identifies, analyses, and reports repeated patterns in order to describe, understand, and interpret a data set (Braun & Clarke, 2006; Clarke & Braun, 2016; Kiger & Varpio, 2020).

Table 2: Descriptive statistics per subsection of the questionnaires from Phase 2

	Mean	Standard Deviation	Count
1. Effectiveness			
1.1 Spatial characteristics	3.9750	1.0121	40
1.2 Visual authenticity	3.8500	1.2359	20
1.3 Interaction with virtual objects	3.4000	1.6248	30
1.4 Consistency of data display	4.7500	0.8874	20
TOTAL Effectiveness	**3.9364**	**1.3092**	**110**
2. Efficiency			
2.1 Ease of navigation and object manipulation	3.8667	1.2579	30
TOTAL Efficiency	**3.8667**	**1.2579**	**30**
3. Satisfaction			
3.1 Physical comfort	4.9000	0.4192	70
3.2 Lack of user frustration	3.9000	1.3379	20
3.3 Attitude and motivation	4.8000	0.5416	30
TOTAL Satisfaction	**4.7083**	**0.7788**	**120**

Figure 4 shows the themes and sub-themes as identified from the results.

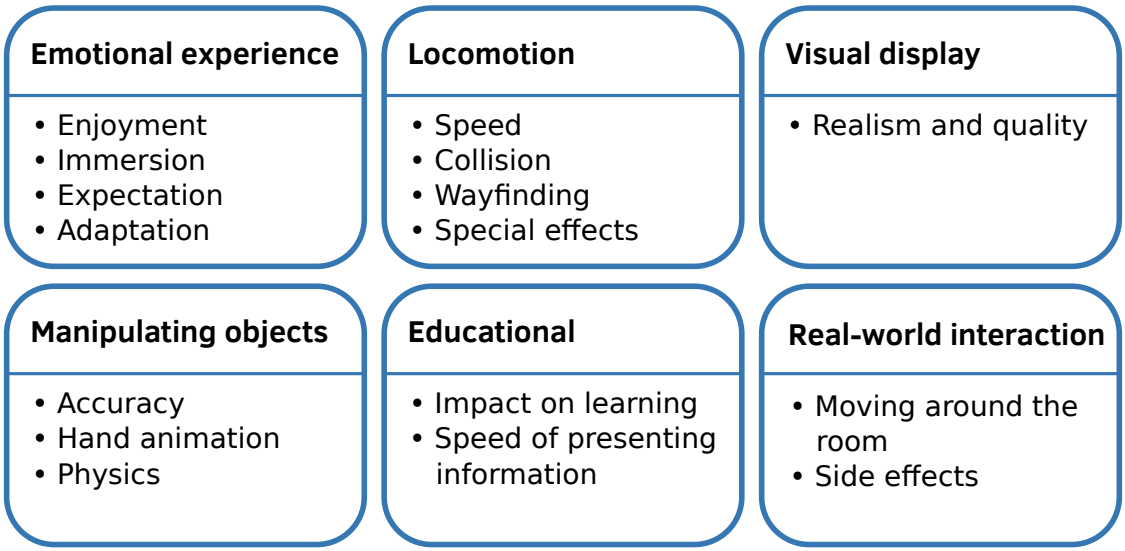


Figure 4: Themes and sub-themes as identified in Phase 2

Figure 5 displays the main themes arising from the semi-structured interviews as a tree map, where the area of each section represents the number of times the theme occurred in the responses in the interviews.

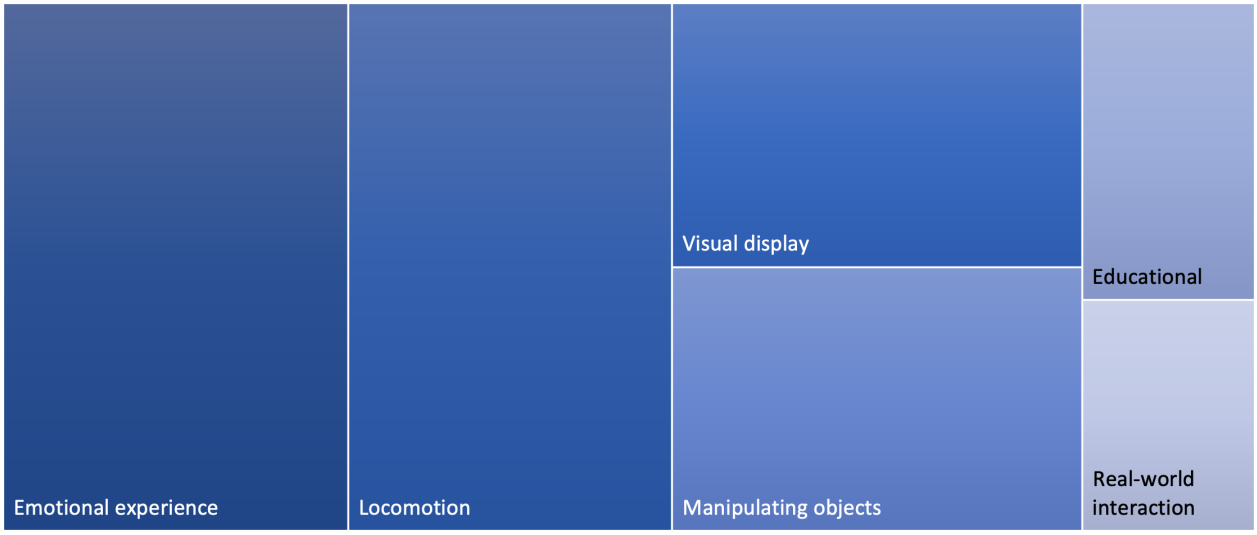


Figure 5: Main themes arising from the interviews shown as a tree map

As can be seen from Figure 5, learners surprisingly commented the most on the overall emotional experience of the VRLE. Aspects highlighted regarding emotional experience can be summarised under the following five categories:

Enjoyment

All the learners commented on the enjoyment of the game.

> *"It was an enjoyable and fun way to learn."* [L2]
>
> *"It was very cool."* [L3]
>
> *"I really enjoyed it."* [L3]
>
> *"I enjoyed it very much."* [L4]

Interest generated

> *"It had a good start with a cliff hanger. It was very nice."* [L10]
>
> *"It was more enjoyable, interesting, and not boring."* [L5]

Immersion

Many learners commented that they felt immersed in the VRLE and felt themselves to be part of the environment.

> *"I felt like I was part of the environment. Like I really was there."* [L1]
>
> *"It was very cool, I felt as if I was really there."* [L8]

https://doi.org/10.18489/sacj.v35i2.17442

"I felt as if I was part of the game." [L10]

Adaptation

A few learners indicated that they had to adapt to the environment. L3 said that she had to get used to how it worked and L10 mentioned that his eyes had to adapt a little. L7 said that

"Something felt strange, I am not sure why."

Expectations

In addition to their emotional experiences, learners had certain expectations of the VRLE before using it.

"I did not expect such good quality," [L1]

and L9 mentioned that he did not know what to expect. He also said that he expected it to be much harder. L5 supported these preconceived expectations of the learners, saying that:

"I expected more problems with navigation, but it was quite easy to use."

Interestingly, one learner commented on other participants' anticipated emotional experience:

"Some people won't like it and not everyone will enjoy using it." [L7]

3.3 Discussion of results

Participants found the VRLE interesting, engaging, and instructive, and they enjoyed the storyline and the challenges. Some of the participants mentioned that they knew exactly what to do; this implies the explanations were at the correct level for learners and that they enjoyed the challenge. They would, nevertheless, have liked a longer game with more interaction and harder challenges. They suggested more experimentation with the magnets and more interaction with other objects as well.

Several shortcomings were also mentioned during both phases of the trials. Many participants noted that the changes and moving around in the VRLE were either too fast or too slow. Furthermore, object manipulation was occasionally erroneous and inaccurate. Interestingly, a few commented on the weightlessness of the objects and noted that not being able to use their hands when picking up an object in the VRLE felt unnatural. The use of gloves with sensors as controllers might be a necessary enhancement when VRLEs are widely used.

Surprisingly, most of participants did not experience significant negative side effects such as motion sickness or claustrophobia. A few mentioned that the elevator that lifted them to the new world was interesting, "cool" or "weird". Another participant commented that she felt very alone in the VRLE with no other people around. She suggested that there should be other people welcoming the learner into the New World.

The need for the facilitator to communicate with the learner while he or she is using the VRLE also became apparent. The learner cannot hear anything apart from what is coming through the headphones connected to the head-mounted display, and the facilitator or teacher cannot assist or direct the learner if needed. A system where the voice of the facilitator could be projected to the learner's headphones would be beneficial. Notably, this will depend on the audio functionality of the headset used.

4 CONTRIBUTIONS

4.1 A refined design model

Before the commencement of the design in Phase 1, a design model was derived from literature for the parts that must be considered when developing a VRLE, namely, the content, the pedagogy, and the technology (seen in Figure 1).

However, throughout the evaluation of the artefact that took place in Phase 2, it was evident that there was another part that was essential to the development of the VRLE. We noted that the user is embedded in the VR environment, therefore, he or she becomes part of it rather than existing as a separate entity (Radianti et al., 2020). In view of this realisation and the feedback regarding the learner's emotional experience of the VRLE, we proposed that the learner should form the central part of the design model, modifying the diagram of the model depicted in Figure 1 to the refined model seen in Figure 6.

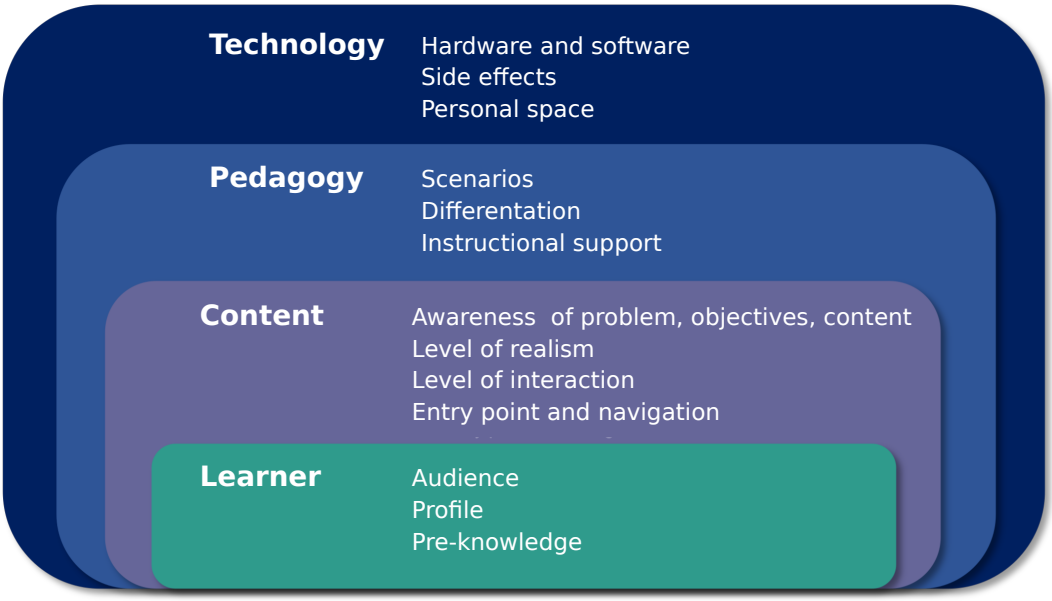


Figure 6: The adapted design model showing the aspects to consider when designing and developing a VRLE

This new model shows that the design of a VRLE should start with identifying the audience, including the demographics of the learners who will use the VRLE, determining the profiles or personas of these learners, and the target audience's expected pre-knowledge or existing conceptual frameworks. After these aspects have been identified, the rest of the VRLE design and development can follow, that is, the decisions related to the Content followed by the Pedagogy, and finally the Technology to support the implementation.

This modification of the design model, to place the learner at the core of the design model, will ensure that suitable content will be identified for presenting in the VRLE. Accordingly, the learners' developmental stage, experience, and skills will lead the design of the realism of the VRLE by using real-world metaphors and wayfinding methods that the learner is comfortable with. For example, a real-world metaphor for 'phone a friend' could be a payphone for an older audience, while for millennials it should be a cellular phone. Similarly, for wayfinding, an older audience would gravitate to a map, whereas millennials would more likely try to use a GPS or a map application. Based on the learners' profiles, scenarios can be developed to complement their interests and experiences. Authentic tasks can be created involving topical current affairs that the specific group of learners can relate to; this can broaden the learners' experiences by applying the knowledge presented in the VRLE to real-world scenarios. By considering the learners' demographics, differentiation according to language and abilities can be created. Pedagogical support should be designed with the learner in mind – while one age group may prefer a cartoon character as a pedagogical agent, others may prefer a visual task list to guide them through the VRLE. Lastly, the learners' demographics should guide the selection of hardware and software, as different age groups have different large and small motor skills that influence the use of hand controllers or buttons.

Developing the VRLE with the learner at the core could lead to an improved learner experience and more successful learning and assessment processes.

4.2 Extending UX to form VLX

The UX of a human-computer system is defined as the quality of a user's experience when interacting with the system. This includes the user's physical, cognitive, and emotional experience. The factors that are considered in measuring this experience vary in the literature and identifying these factors is an ongoing process in various studies (International Organization for Standardization, 2018; Moczarny et al., 2012; Nikou & Economides, 2019; Rhiu et al., 2020; Rogers et al., 2002). However, certain design aspects, like authenticity, immersion, and instructional support, that influenced the virtual learner experience (VLX) while using the VRLE have not been considered as part of UX in the current literature, and do not form part of the UX of general computer systems. Therefore, we propose that the definition of the UX of a virtual learning system should be extended to include learner-specific aspects. This extended definition of UX will be referred to in the rest of this study as VLX, where the quality of this experience is underpinned by the quality of the learning process, as contained in the learning environment.

During the DSR iterative design process that was followed in this study, the learners commented extensively on their emotional experience of the platform. The factors that they commented on that form part of the existing definition of UX included their emotional enjoyment, their expectations, and their adaption to the environment. However, they also commented on factors not included in current UX definitions, namely, their immersion in the scenarios,

> *"I felt like I was part of the environment. Like I really was there."* [L1]

the authenticity of the tasks,

> *"There was a story and a realistic goal – that was very nice,"* [P4]
>
> *"It had a good start with a cliff-hanger,"* [L10]

and the guidance they received,

> *"It was nice that they explain exactly what was going on."* [P4]

From the literature studies and the lessons learnt from the DSR process, the following three factors are proposed as components of VLX, as they influence the quality of the learning experience:

Authenticity

Authentic scenarios based on real-world problems and tasks that concern topical current affairs may improve the transfer of learning from the learning environment to the real world (Çakiroğlu & Gökoğlu, 2019a, 2019b; Craig et al., 2009; Crosier et al., 2002; Ritz & Buss, 2016; Schott & Marshall, 2018). Authentic tasks allow the learner to experience real-world situations where they can think innovatively and experiment with solutions to problems while being in a safe environment.

Immersion and engagement

When a learner is immersed in the learning scenario, his or her engagement with the learning material improves and may lead to better conceptual understanding and transfer of learning (Çakiroğlu & Gökoğlu, 2019a, 2019b; Craig et al., 2009; Crosier et al., 2002; Huang et al., 2018; Ritz & Buss, 2016; Schott & Marshall, 2018). Engagement is closely linked to interaction, and a high level of interaction between the learner and the learning material may lead to a better conceptual understanding (Kavanagh et al., 2017; Parong & Mayer, 2018; Pigatt & Braman, 2016).

https://doi.org/10.18489/sacj.v35i2.17442

Pedagogical support

Instructional support in the form of pedagogical agents is essential in learning environments, where a physical teacher takes on the role of a facilitator and is not directly involved in the learning process. These pedagogical agents can guide the learner in the learning process, can model desired behaviour and can provide scaffolding for developing new skills (Chen et al., 2004; Clarebout & Elen, 2007; Mamun et al., 2020; Minocha & Hardy, 2016; Schroeder, 2016). Through their presence and interaction with the learners, these agents can provide emotional support and eliminate feelings of loneliness in the VRLE.

These three additional components of VLX can be visualised with an extended definition of UX, as can be seen in Figure 7.

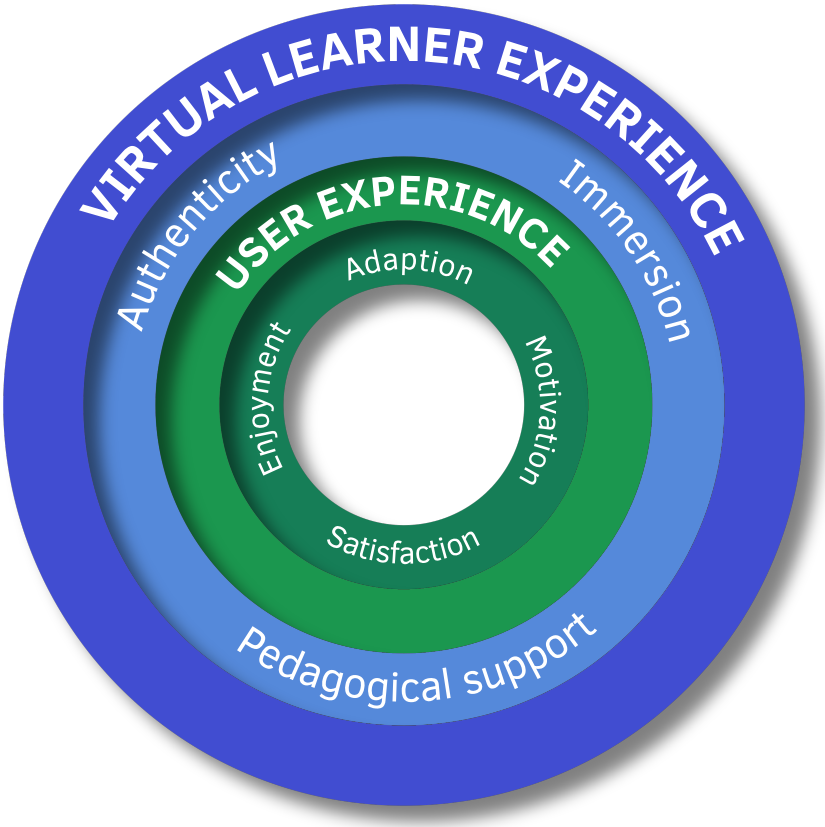


Figure 7: Extending UX to VLX with additional factors that emerged from this study

The perception that the applicable target audience, that is, the typical learner profile, should influence the design and the development of the VRLE became increasingly clear as this study progressed. The learners should, thus, be seen as the starting point for the design and development of the VRLE, and the VRLE should be built with the learners' demographics,

characteristics, and existing conceptual frameworks in mind. The factors influencing VLX that arose from this study were identified as authenticity, immersion, and pedagogical support.

4.3 VRLE guidelines for VLX

The lessons learnt from Phases 1 and 2 were synthesised with guidelines and frameworks from existing literature, and a new set of guidelines were constructed to answer the main question – 'What are the UX design aspects of a virtual reality environment for the assessment of learner knowledge transfer in science education focusing on magnetism?'

These guidelines were practically evaluated through the DSR cycles, and they can now be used by educational material designers when developing an effective, efficient, and satisfactory VRLE focusing on VLX for assessment in the secondary-school science classroom.

To structure the guidelines, the modified design model from Figure 6 was used as a starting point and the guidelines were divided into the four parts identified, namely, the learner, the content, the pedagogy, and the technology.

The learner forms the core of the entire process of design and development. The starting point of the VRLE design should be the identification and definition of the prospective learner audience. The learner's experience, engagement, motivation, and well-being must be considered as of utmost importance and should be the thread through the whole design and development process.

The guidelines then focus on the content of the VRLE, which together with the context of the VRLE, has an integral influence on the enjoyment and engagement of the learners. The objectives and goals of the VRLE should be clearly identified and presented in an engaging storyline depicted in real-world scenarios with appropriately complex and authentic tasks.

The next part of the design model is the pedagogy. When considering the use of a VRLE for assessing the transfer of learning to the real world, the pedagogical aspects of the VRLE should be carefully designed to ensure that the assessment is reliable and valid. Clear objectives and goals should be determined with help being always accessible.

Lastly, the technology used to implement the VRLE envelops all the previous parts. Without appropriate hardware and software for the implementation of the VRLE, the effectiveness and efficiency of putting the learner into the centre of VRLEs would be impaired. Wearable hardware should be comfortable, adjustable, and not cause fatigue. The VRLE should be easily mastered with intuitive controls and natural navigation. Physical side-effects should always be considered and mitigated as far as possible to accommodate learners with different physical characteristics.

The final guidelines, structured with the learner as the focus/centre of the design model in mind, are shown in Table 3.

Table 3: Guidelines for an effective and efficient virtual reality environment for the assessment of knowledge transfer in science education

Learner
- The VRLE should be aimed at a specific audience with pre-identified learner profiles and levels of pre-knowledge. - Learners' motivation and level of enjoyment should be considered throughout the design and development process. - The learner must be able to control and interact with the VRLE in a natural manner. - The learner should be able to take responsibility for his or her own assessment or task progress. - The tasks that the learner should complete must be clearly identifiable. - The learner's progress and results should be stored and displayed throughout the VRLE. - The VRLE should offer differentiated content based on certain learner characteristics. - The learner should be immersed in the environment. - The learner's comfort and personal space is of utmost importance and must be considered when designing and developing the VRLE. - Learners should have the option to communicate and collaborate with their peers or teachers.
Content
- Employ real-world scenarios with complex, authentic, significant tasks. - The objectives and goals should be clear and easily identified. - The VRLE should include a captivating storyline. - The VRLE must include background content on the tasks that the learner might need. - The level of interaction should enable the learner to engage with the learning material. - The visual representation of the environment and objects in it should be pleasing, accurate, and consistent. - There should be realistic interaction with objects in the VRLE. - The environment and its behaviour should be consistent with the learner's conceptual framework. - The subject content should be presented in learner-paced segments. - Real-world metaphors that the learners are familiar with should be used. - The colours that are used to represent different concepts must be consistent with common use.
Pedagogy
- Outcomes and assessment tasks must be aligned, clearly stated, and consistent. - Assessment should be practical and sustainable. - Instructions should be clear and consistent throughout the VRLE.

[Continued …]

Table 3: […continued]

Pedagogy
- Help should be accessible at all times. - Scaffolding and feedback should be consistently applied in easy-to-understand language. - The subject matter must be complete and accurate.
Technology
- Appropriate hardware and software should be selected, keeping the objectives and the audience of the VRLE in mind. - Use of the VRLE should be intuitive and easily mastered. - The learner should be able to control and interact with the VRLE in an intuitive, natural manner. - The hardware should be always easily adjustable and comfortable. - Input devices should be easily manipulated. - Learners should not be able to skip VRLE-specific tutorials that will familiarise them with the use of the VRLE. - The VRLE should be reliable and special consideration must be given to the implementation of the control flow of the VRLE. Specialised models such as finite-state machines can assist in simplifying the implementation, leading to an improved system. - The system must respond immediately and consistently to a learner's actions. - There must be boundaries to limit a learner's movement to keep them from entering out-of-bounds areas. - Navigation and wayfinding should be natural and simple. - There should be minimum distortion in visual and audio information. - Physical side-effects of using the VRLE should be minimised and monitored throughout the design, development, and implementation of the VRLE.

5 CONTEXTUALISATION

To contextualise the value of our findings, we considered studies that have investigated aspects of VRLEs during the past 12 months and now present a selection of those findings. A few of those will now be discussed.

Makransky et al. (2019) investigated the effectiveness of immersive VR as a training environment and obtained their seminal results by comparing the performance of learners studying in three environments, namely, immersive VR, desktop VR, and paper-based training. They concluded that the performance of the different groups of learners did not differ on the immediate retention test, but there was a significant improvement in the transfer of learning to experience in a physical lab in the group that received training in immersive VR.

Concannon et al. (2020) studied the possibility that experience with simulated practical exams lowered occupational therapy students' anxiety. They created a virtual clinic with VR

simulation that featured a clinic and a standardised patient whom students could interview in natural language. In this study, they concluded that the students who participated in the VR simulation, as part of their examination preparation, had a significantly lower anxiety level when conducting their actual practical exams.

Sun et al. (2019) investigated the use of immersive VR for assessment in higher education. They concluded that students preferred to use the VRLE, found it more engaging, and had an increased sense of involvement. This is supported by the study by Akman and Çakır (2020), focusing on the engagement and retention of learning in the primary school mathematics classroom.

Yu's (2021) systematic review found that overall learning outcomes and achievements could be significantly improved by VR. Furthermore, they concluded that the design of the VRLE may directly affect the influence of the VRLE on learning. This also supports the importance of this study, namely, to ensure the optimum design of a VRLE with the learner at the core of the design.

These studies provide evidence to support the value of using VRLEs to support knowledge transfer to practical situations, as well as reducing anxiety in practical examinations. However, none of the recent studies addressed the gap in terms of VRLE design guidelines for assessing knowledge transfer in the science classroom, and they support the need for expansive and clear design guidelines to ensure that the positive effect of the VRLE on learning is maximised.

6 DISCUSSION AND CONCLUSION

During the initial investigation of the literature in 2018 when this study commenced, it was found that the focus of education was shifting, with learning in the 21st century becoming increasingly characterised by a large number of non-recurrent skills that have to be applied flexibly to novel situations (Bossard et al., 2008; Guàrdia et al., 2017; National Research Council, 2012; Spector et al., 2016; van Gog et al., 2008). Therefore, the proposal was that assessment should move away from the current linear model, which focuses on content and is isolated from real-life situations, towards authentic, real-world assessment that enables learners to experience problem-solving in a safe virtual environment (Andrews, 2002; Guàrdia et al., 2017; Heady, 2000; Idrissi et al., 2017; Roussou et al., 2006; Spector et al., 2016). The COVID-19 pandemic changed education in an unprecedented manner, resulting in a shift to online classrooms (UNESCO, 2020). In this shift, the need for effective e-assessments was brought to many pedagogists' attention. Educational material designers now have the motivation to develop e-assessments that not only include digital versions of closed questions, but also more sophisticated tasks and skill- or competency-based assessments (Adedoyin & Soykan, 2020). These fundamental changes to the core of education now call for a renewed focus on e-assessment to ensure that the highest levels of requirements are met.

This research concentrated on the UX design aspects of a VRLE for the assessment of learner knowledge transfer in science education. The findings from the evaluation of the artefact obtained in Phase 2 suggest the need for a model where the learner is at the core/centre of the design of the learning environment. This insight is concretised by describing VLX as an extended view of UX, where it includes the quality of a learner's experience when interacting with a learning environment. VLX is defined in this study as the virtual learner experience, a focused view of UX including learning-specific aspects such as authenticity, immersion, and instructional support, in addition to the traditional aspects of UX. This implies that the quality of the learning process, as contained in the learning environment, forms the basis of the learners' experience in terms of usability. The theoretical contributions of this research include the evidence-based VLX design model and the VRLE design guidelines for the assessment of knowledge transfer in science education. More research is required to expand these learning-specific aspects to solidify the description of VLX and simplify the design and development process of VRLEs.

ACKNOWLEDGEMENT

This paper is based on the research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation of South Africa (Grant No. 98564).

References

Adedoyin, O. B., & Soykan, E. (2020). Covid-19 pandemic and online learning: The challenges and opportunities. *Interactive Learning Environments*, *31*(2), 863–875. https://doi.org/10.1080/10494820.2020.1813180

Akcayir, G., & Epp, C. D. (2020). *Designing, deploying, and evaluating virtual and augmented reality in education*. IGI Global. https://doi.org/10.4018/978-1-7998-5043-4

Akman, E., & Çakır, R. (2020). The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics. *Interactive Learning Environments*, *31*(3), 1467–1484. https://doi.org/10.1080/10494820.2020.1841800

Alakrash, H. M., & Razak, N. A. (2022). Education and the fourth industrial revolution: Lessons from COVID-19. *Computers, Materials & Continua*, *70*(1), 951–962. https://doi.org/10.32604/cmc.2022.014288

Albert, B., & Tullis, T. (2013). *Measuring the user experience: Collecting, analysing, and presenting usability metrics* (2nd ed.). Morgan Kaufmann. https://shop.elsevier.com/books/measuring-the-user-experience/albert/978-0-12-415781-1

Amankwah-Amoah, J., Khan, Z., Wood, G., & Knight, G. (2021). COVID-19 and digitalization: The great acceleration. *Journal of Business Research*, *136*, 602–611. https://doi.org/10.1016/j.jbusres.2021.08.011

Andrews, L. (2002). Transfer of learning: A century later. *Journal of Thought*, *37*(2), 63–72. http://www.jstor.org/stable/42590275

Bevilacque, F. (2013). Finite-state machines: Theory and implementation. https://gamedevelopment.tutsplus.com/tutorials/finite-state-machines-theory-and-implementation--gamedev-11867

Bilonozhko, N., & Syzenko, A. (2020). Effective reading strategies for Generation Z using authentic texts. *Arab World English Journal*, (2), 121–130. https://doi.org/10.24093/awej/elt2.8

Bogusevschi, D., Muntean, C., & Muntean, G. (2020). Teaching and learning physics using 3D virtual learning environment: A case study of combined virtual reality and virtual laboratory in secondary school. *Journal of Computers in Mathematics and Science Teaching*, *39*(1), 5–18. https://www.learntechlib.org/primary/p/210965/

Bosman, I. d., de Beer, K., & Bothma, T. J. (2021). Creating pseudo-tactile feedback in virtual reality using shared crossmodal properties of audio and tactile feedback. *South African Computer Journal*, *33*(1). https://doi.org/10.18489/sacj.v33i1.883

Bossard, C., Kermarrec, G., Buche, C., & Tisseau, J. (2008). Transfer of learning in virtual environments: A new challenge? *Virtual Reality*, *12*(3), 151–161. https://doi.org/10.1007/s10055-008-0093-y

Bourg, D. M., & Seemann, G. (2004). *AI for game developers*. O'Reilly Media, Inc. https://www.oreilly.com/library/view/ai-for-game/0596005555/

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Çakiroğlu, Ü., & Gökoğlu, S. (2019a). A design model for using virtual reality in behavioral skills training. *Journal of Educational Computing Research*, *57*(7), 1723–1744. https://doi.org/10.1177/0735633119854030

Çakiroğlu, Ü., & Gökoğlu, S. (2019b). Development of fire safety behavioral skills via virtual reality. *Computers & Education*, *133*, 56–68. https://doi.org/10.1016/j.compedu.2019.01.014

Chen, C. J., Toh, S. C., & Fauzy, W. M. (2004). The theoretical framework for designing desktop virtual reality-based learning environments. *Journal of Interactive Learning Research*, *15*(2), 147–167. https://www.learntechlib.org/primary/p/12841/

Chen, C. J. (2006). The design, development and evaluation of a virtual reality based learning environment. *Australasian Journal of Educational Technology*, *22*(1). https://doi.org/10.14742/ajet.1306

Clarebout, G., & Elen, J. (2007). In search of pedagogical agents' modality and dialogue effects in open learning environments. *E-Journal of Instructional Science and Technology*, *10*(1). https://eric.ed.gov/?id=EJ846724

Clarke, V., & Braun, V. (2016). Thematic analysis. *The Journal of Positive Psychology*, *12*(3), 297–298. https://doi.org/10.1080/17439760.2016.1262613

Concannon, B. J., Esmail, S., & Roberts, M. R. (2020). Immersive virtual reality for the reduction of state anxiety in clinical interview exams: Prospective cohort study. *JMIR Serious Games*, *8*(3), e18313. https://doi.org/10.2196/18313

Craig, A. B., Sherman, W. R., & Will, J. D. (2009). *Developing virtual reality applications*. Elsevier. https://doi.org/10.1016/c2009-0-20103-6

Crosier, J. K., Cobb, S., & Wilson, J. R. (2002). Key lessons for the design and integration of virtual environments in secondary science. *Computers & Education*, *38*(1-3), 77–94. https://doi.org/10.1016/s0360-1315(01)00075-6

Desurvire, H., & Kreminski, M. (2018). Are game design and user research guidelines specific to virtual reality effective in creating a more optimal player experience? Yes, VR PLAY. In *Design, user experience, and usability: Theory and practice* (pp. 40–59). Springer International Publishing. https://doi.org/10.1007/978-3-319-91797-9_4

Donath, D., & Regenbrecht, H. (1995). VRAD (Virtual Reality Aided Design) in the early phases of the architectural design process. *Sixth International Conference on Computer-Aided Architectural Design Futures*, 313–322. https://papers.cumincad.org/cgi-bin/works/paper/8955

Erebak, S., & Turgut, T. (2021). Anxiety about the speed of technological development: Effects on job insecurity, time estimation, and automation level preference. *The Journal of High Technology Management Research*, *32*(2), 100419. https://doi.org/https://doi.org/10.1016/j.hitech.2021.100419

Falloon, G. (2019). From simulations to real: Investigating young students' learning and transfer from simulations to real tasks. *British Journal of Educational Technology*, *51*(3), 778–797. https://doi.org/10.1111/bjet.12885

Farra, S., Miller, E. T., Hodgson, E., Cosgrove, E., Brady, W., Gneuhs, M., & Baute, B. (2016). Storyboard development for virtual reality simulation. *Clinical Simulation in Nursing*, *12*(9), 392–399. https://doi.org/10.1016/j.ecns.2016.04.002

Górski, F., Buń, P., Wichniarek, R., Zawadzki, P., & Hamrol, A. (2016). Effective design of educational virtual reality applications for medicine using knowledge-engineering techniques. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2). https://doi.org/10.12973/eurasia.2017.00623a

Guàrdia, L., Crisp, G., & Alsina, I. (2017). Trends and challenges of e-assessment to enhance student learning in higher education. In *Innovative practices for higher education assessment and measurement* (pp. 36–56). IGI Global. https://doi.org/10.4018/978-1-5225-0531-0.ch003

Heady, J. E. (2000). Assessment – a way of thinking about learning – now and in the future. *Journal of College Science Teaching*, *29*(6), 415. https://www.proquest.com/scholarly-journals/assessment-way-thinking-about-learning-now-future/docview/200316998/se-2

Heng, L., & McColl, B. (2021). *Mathematics for future computing and communications*. Cambridge University Press. https://doi.org/10.1017/9781009070218

Herrington, J., Reeves, T. C., & Oliver, R. (2013, May). Authentic learning environments. In *Handbook of research on educational communications and technology* (pp. 401–412). Springer New York. https://doi.org/10.1007/978-1-4614-3185-5_32

Huang, Y.-C., Backman, S. J., Backman, K. F., McGuire, F. A., & Moore, D. (2018). An investigation of motivation and experience in virtual learning environments: A self-determination theory. *Education and Information Technologies*, *24*(1), 591–611. https://doi.org/10.1007/s10639-018-9784-5

Idrissi, M. K., Hnida, M., & Bennani, S. (2017). Competency-based assessment. In *Innovative practices for higher education assessment and measurement* (pp. 57–78). IGI Global. https://doi.org/10.4018/978-1-5225-0531-0.ch004

International Organization for Standardization. (2018). ISO 9241-11:2018, Ergonomics of human-system interaction – Part 11: Usability: Definitions and concepts. https://www.iso.org/standard/63500.html

Jeffries, P. R. (2005). A framework for designing, implementing, and evaluating simulations used as teaching strategies in nursing. *Nursing Education Perspectives*, *26*(2), 96–103. https://journals.lww.com/neponline/abstract/2005/03000/a_framework_for_designing,_implementing,_and.9.aspx

Jiang, Y., Paquette, L., Baker, R. S., & Clarke-Midura, J. (2015). Comparing novice and experienced students within virtual performance assessments. *Proceedings of the 8th International Conference on Educational Data Mining*, 136–143. https://eric.ed.gov/?id=ED560561

Joint Information Systems Committee. (2010). Effective assessment in a digital age. https://issuu.com/jiscinfonet/docs/jisc_effective_assessment_in_a_digital_age_2010

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of virtual reality in education. *Themes in Science and Technology Education*, *10*(2), 85–119. https://www.learntechlib.org/p/182115/

Kennedy-Clark, S., & Wheeler, P. (2014). Using discourse analysis to assess student problem-solving in a virtual world. In *Cases on the assessment of scenario and game-based virtual worlds in higher education* (pp. 211–253). IGI Global. https://doi.org/10.4018/978-1-4666-4470-0.ch007

Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical Teacher*, *42*(8), 846–854. https://doi.org/10.1080/0142159x.2020.1755030

Lewis, J. R. (1994). Sample sizes for usability studies: Additional considerations. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *36*(2), 368–378. https://doi.org/10.1177/001872089403600215

Liu, M., Su, S., Liu, S., Harron, J., Fickert, C., & Sherman, B. (2016). Exploring 3D immersive and interactive technology for designing educational learning experiences. In *Virtual and augmented reality* (pp. 1088–1106). IGI Global. https://doi.org/10.4018/978-1-5225-5469-1.ch051

Madathil, K. C., Frady, K., Hartley, R., Bertrand, J., Alfred, M., & Gramopadhye, A. (2017). An empirical study investigating the effectiveness of integrating virtual reality-based

case studies into an online asynchronous learning environment. *Computers in Education Journal*, *8*(3), 1–10. https://coed.asee.org/2017/07/07/an-empirical-study-investigating-the-effectiveness-of-integrating-virtual-reality-based-case-studies-into-an-online-asynchronous-learning-environment/

Mahdi, O., Oubahssi, L., Piau-Toffolon, C., & Iksal, S. (2018). Towards design and operationalization of pedagogical situations in the VRLEs. *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*, 400–402. https://doi.org/10.1109/icalt.2018.00095

Makhkamova, A., Exner, J.-P., Greff, T., & Werth, D. (2020). Towards a taxonomy of virtual reality usage in education: A systematic review. In *Augmented reality and virtual reality* (pp. 283–296). Springer International Publishing. https://doi.org/10.1007/978-3-030-37869-1_23

Makransky, G., Borre-Gude, S., & Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, *35*(6), 691–707. https://doi.org/10.1111/jcal.12375

Mamun, M. A. A., Lawrie, G., & Wright, T. (2020). Instructional design of scaffolded online learning modules for self-directed and inquiry-based learning environments. *Computers & Education*, *144*, 103695. https://doi.org/10.1016/j.compedu.2019.103695

McHaney, R., Reiter, L., & Reychav, I. (2018). Immersive simulation in constructivist-based classroom e-learning. *International Journal on E-Learning*, *17*(1), 39–64. https://www.learntechlib.org/primary/p/149930/

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education*, *56*(3), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020

Minocha, S., & Hardy, C. (2016). Navigation and wayfinding in learning spaces in 3D virtual worlds. In M. J. W. Lee, B. Tynan, B. Dalgarno & S. Gregory (Eds.), *Learning in virtual worlds: Research and applications* (pp. 5–41). AU Press, Edmonton, Canada. https://doi.org/10.1145/2071536.2071570

Minocha, S., & Reeves, A. J. (2010). Interaction design and usability of learning spaces in 3D multi-user virtual worlds. In *Human work interaction design: Usability in social, cultural and organizational contexts* (pp. 157–167). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-11762-6_13

Moczarny, I. M., de Villiers, M. R., & van Biljon, J. A. (2012). How can usability contribute to user experience? *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference*, 216–225. https://doi.org/10.1145/2389836.2389862

National Research Council. (2012, December). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Academies Press. https://doi.org/10.17226/13398

Nemec, M., Fasuga, R., Trubac, J., & Kratochvil, J. (2017). Using virtual reality in education. *2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, 1–6. https://doi.org/10.1109/iceta.2017.8102514

Nikou, S. A., & Economides, A. A. (2019). A comparative study between a computer-based and a mobile-based assessment. *Interactive Technology and Smart Education*, *16*(4), 381–391. https://doi.org/10.1108/itse-01-2019-0003

Novak, J. D., Mintzes, J. I., & Wandersee, J. H. (2005). Learning, teaching, and assessment: A human constructivist perspective. In *Assessing science understanding* (pp. 1–13). Elsevier. https://doi.org/10.1016/b978-012498365-6/50003-2

Özgen, D. S., Afacan, Y., & Sürer, E. (2019). Usability of virtual reality for basic design education: A comparative study with paper-based design. *International Journal of Technology and Design Education*, *31*(2), 357–377. https://doi.org/10.1007/s10798-019-09554-0

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785–797. https://doi.org/10.1037/edu0000241

Pellegrino, J. (2010). Technology and formative assessment. In *International Encyclopedia of Education* (pp. 42–47). Elsevier. https://doi.org/10.1016/b978-0-08-044894-7.00700-4

Penichet, V. M., Peñalver, A., & Gallud, J. A. (Eds.). (2013). *New trends in interaction, virtual reality and modeling*. Springer London. https://doi.org/10.1007/978-1-4471-5445-7

Pigatt, Y., & Braman, J. (2016). Increasing student engagement through virtual worlds. In *Emerging tools and applications of virtual reality in education* (pp. 75–94). IGI Global. https://doi.org/10.4018/978-1-4666-9837-6.ch004

Portman, M., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems*, *54*, 376–384. https://doi.org/10.1016/j.compenvurbsys.2015.05.001

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Rhiu, I., Kim, Y. M., Kim, W., & Yun, M. H. (2020). The evaluation of user experience of a human walking and a driving simulation in the virtual reality. *International Journal of Industrial Ergonomics*, *79*, 103002. https://doi.org/10.1016/j.ergon.2020.103002

Ritz, L. T., & Buss, A. R. (2016). A framework for aligning instructional design strategies with affordances of CAVE immersive virtual reality systems. *TechTrends*, *60*(6), 549–556. https://doi.org/10.1007/s11528-016-0085-9

Rogers, Y., Sharp, H., & Preece, J. (2002). *Interaction design: Beyond human-computer interaction*. John Wiley & Sons. https://www.wiley.com/en-us/Interaction+Design%3A+Beyond+Human+Computer+Interaction%2C+6th+Edition-p-9781119901099

Rosen, Y. (2014). Thinking tools in computer-based assessment: Technology enhancements in assessments for learning. *Educational Technology*, *54*(1), 30–34. http://www.jstor.org/stable/44430233

Roussou, M., Oliver, M., & Slater, M. (2006). The virtual playground: An educational virtual reality environment for evaluating interactivity and conceptual learning. *Virtual Reality*, *10*(3-4), 227–240. https://doi.org/10.1007/s10055-006-0035-5

Schott, C., & Marshall, S. (2018). Virtual reality and situated experiential education: A conceptualization and exploratory trial. *Journal of Computer Assisted Learning*, *34*(6), 843–852. https://doi.org/10.1111/jcal.12293

Schroeder, N. L. (2016). Pedagogical agents for learning. In *Emerging tools and applications of virtual reality in education* (pp. 216–238). IGI Global. https://doi.org/10.4018/978-1-4666-9837-6.ch010

Serafin, S., Erkut, C., Kojs, J., Nordahl, R., & Nilsson, N. C. (2016). Virtual reality musical instruments. *Proceedings of the Audio Mostly 2016*, 266–271. https://doi.org/10.1145/2986416.2986431

Shavelson, R. J., Baxter, G. P., & Pine, J. (1991). Performance assessment in science. *Applied Measurement in Education*, *4*(4), 347–362. https://doi.org/10.1207/s15324818ame0404_7

Snowdon, C. M., & Oikonomou, A. (2018). Analysing the educational benefits of 3D virtual learning environments. *European Conference on E-Learning*, 513–522. https://www.proquest.com/conference-papers-proceedings/analysing-educational-benefits-3d-virtual/docview/2154983229/se-2

Sokhanvar, Z., Salehi, K., & Sokhanvar, F. (2021). Advantages of authentic assessment for improving the learning experience and employability skills of higher education students: A systematic literature review. *Studies in Educational Evaluation*, *70*, 101030. https://doi.org/10.1016/j.stueduc.2021.101030

Spector, J. M., Ifenthaler, D., Sampson, D., Yang, L., Mukama, E., Warusavitarana, A., Dona, K. L., Eichhorn, K., Fluck, A., Huang, R., Bridges, S., Lu, J., Ren, Y., Gui, X., Deneen, C. C., Diego, J. S., & Gibson, D. C. (2016). Technology enhanced formative assessment for 21st century learning. *Journal of Educational Technology & Society*, *19*(3), 58–71. http://www.jstor.org/stable/jeductechsoci.19.3.58

Steiber, A. (2014). *The Google model: Managing continuous innovation in a rapidly changing world*. Springer, London. https://doi.org/10.1007/978-3-319-04208-4

Steynberg, J., van Biljon, J., & Pilkington, C. (2020). Design aspects of a virtual reality learning environment to assess knowledge transfer in science. In *Lecture notes in Computer Science* (pp. 306–316). Springer International Publishing. https://doi.org/10.1007/978-3-030-63885-6_35

Sun, B., Chikwem, U., & Nyingifa, D. (2019). VRLearner: A virtual reality based assessment tool in higher education. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. https://doi.org/10.1109/vr.2019.8798129

Tinoca, L., Pereira, A., & Oliveira, I. (2014). A conceptual framework for e-assessment in higher education. In *Handbook of research on transnational higher education* (pp. 652–673). IGI Global. https://doi.org/10.4018/978-1-4666-4458-8.ch033

UNESCO. (2020). Education: From disruption to recovery. https://www.unesco.org/en/covid-19/education-disruption-recovery

Väätäjä, H., Koponen, T., & Roto, V. (2009). Developing practical tools for user experience evaluation: A case from mobile news journalism. *European Conference on Cognitive Ergonomics: Designing beyond the Product – Understanding Activity and User Experience in Ubiquitous Environments*, 1–8. https://dl.acm.org/doi/10.5555/1690508.1690539

van Gog, T., Sluijsmans, D. M. A., Joosten-ten Brinke, D., & Prins, F. J. (2008). Formative assessment in an online learning environment to support flexible on-the-job learning in complex professional domains. *Educational Technology Research and Development*, *58*(3), 311–324. https://doi.org/10.1007/s11423-008-9099-0

Vergara, D., Rubio, M., & Lorenzo, M. (2017). On the design of virtual reality learning environments in engineering. *Multimodal Technologies and Interaction*, *1*(2), 11. https://doi.org/10.3390/mti1020011

Virzi, R. A. (1992). Refining the test phase of usability evaluation: How many subjects is enough? *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *34*(4), 457–468. https://doi.org/10.1177/001872089203400407

Vos, L. (2015). Simulation games in business and marketing education: How educators assess student learning from simulations. *The International Journal of Management Education*, *13*(1), 57–74. https://doi.org/10.1016/j.ijme.2015.01.001

World Economic Forum. (2020). Jobs of tomorrow. https://www.weforum.org/reports/jobs-of-tomorrow-mapping-opportunity-in-the-new-economy/

Yu, Z. (2021). A meta-analysis of the effect of virtual reality technology use in education. *Interactive Learning Environments*, 1–21. https://doi.org/10.1080/10494820.2021.1989466

Zawacki-Richter, O., & Latchem, C. (2018). Exploring four decades of research in Computers & Education. *Computers & Education*, *122*, 136–152. https://doi.org/https://doi.org/10.1016/j.compedu.2018.04.001

Zhou, Y., Ji, S., Xu, T., & Wang, Z. (2018). Promoting knowledge construction: A model for using virtual reality interaction to enhance learning. *Procedia Computer Science*, *130*, 239–246. https://doi.org/10.1016/j.procs.2018.04.035

Zuiker, S. J. (2016). Game over: Assessment as formative transitions through and beyond playful media. *Educational Technology*, *56*(3), 48–53. http://www.jstor.org/stable/44430493

SACJ 35(2) December 2023
Research Article

Online Platform Privacy Policies: An Exploration of Users' Perceptions, Attitudes and Behaviours Online

Kimberley Mugadza, Gwamaka Mwalemba

University of Cape Town, Private Bag X3 Rondebosch, Cape Town, 7701

ABSTRACT

In January 2021, Meta (then Facebook) published an update to its WhatsApp privacy policy which included, among other things, a decision to share some user data with Facebook. This action, together with previous events like the notorious Cambridge-Analytica data breach, has sparked debates about the protection of online privacy, specifically the balance of rights and responsibilities relevant to the protection of social media user data. This qualitative study contributes to that debate by exploring the perceptions and reactions of South African WhatsApp users to these policy changes. The findings highlight the significance of platforms like WhatsApp in the daily socio-economic activities of users in developing countries. This reliance on social media for communication and access to vital information creates an imbalance of power between users and platform owners. The situation is worsened by the lack of effective regulatory frameworks that governments and institutions in developing countries can use to enforce their privacy laws, leaving users vulnerable to potential exploitation from digital platforms. This study contributes to the broader discourse on safeguarding online privacy as Western technology companies continue to gain access to data that is generated by an ever-increasing global user base.

Keywords social media, online privacy, consumer behaviour, WhatsApp

Categories • **Information Systems** ∼ **Information systems applications, Collaborative and social computing systems and tools, Social networking sites** • **Social and Professional Topics** ∼ **Computing/technology policy, Privacy Policies**

Email
Kimberley Mugadza – mgdkim001@myuct.ac.za,
Gwamaka Mwalemba – gt.mwalemba@uct.ac.za (CORRESPONDING)

Article history
Received: 29 January 2023
Accepted: 2 November 2023
Online: 14 December 2023

1 INTRODUCTION

A person's digital presence is expanding continuously as more aspects of our daily lives migrate online, particularly onto social media. The rise of social networking sites (SNSs) has changed the way in which people communicate and conduct business on a global scale (Abbas Naqvi et al., 2020). Not only have SNSs become the predominant online platforms for marketing and networking, they have also become widely viewed as the most useful, cost-effective, and popular internet technology tool for reaching consumers (Duggan et al., 2015). As presented by

Mugadza, K., and Mwalemba, G. (2023). Online Platform Privacy Policies: An Exploration of Users' Perceptions, Attitudes and Behaviours Online . *South African Computer Journal* 35(2), 78–96. https://doi.org/10.18489/sacj.v35i2.17443

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

Perrin (2015), SNSs were initially perceived as a simple and functional way for people to build professional networks online. SNSs have evolved since then as companies recognised opportunities for commercialisation. There is now no single definition of what qualifies as an SNS, but it is loosely defined as a community on an online platform that sees users with common interests and needs sharing information, improving productivity, exchanging news and insights, and maintaining a multichannel platform for the retailing of goods and services (Hashimzade et al., 2014). With the use of familiar, convenient, and user-friendly interfaces, people now prefer to use SNSs as their primary means of communication.

The most used social media applications have now become applications like WhatsApp that allow users to send real-time text and multimedia messages to their peers at no cost (Church & de Oliveira, 2013). These types of applications have become the most common social media platforms of the 21st century due to their convenience. However, it must be noted that one of the most prominent issues arising from using these types of applications is that users are exposed to large volumes of unregulated messages or information (Ahad & Lim, 2014; Nobre et al., 2022). Data from a study conducted by Montag et al. (2015) showed that the use of WhatsApp accounted for 19,83% of all smartphone behaviour. This was compared to Facebook usage at the time, which amounted to 9.38%.

In recent years, several privacy-related debates and events have been covered extensively in the media. Many of these events were related to companies with a significant influence over the information technology (IT) industry such as Facebook and Google (Fiesler & Hallinan, 2018). Due to these recurring privacy-related events and the widespread consumption of social media and digital content, technology designers and policymakers are now obliged to remain more accountable to their users. Consequently, these policymakers and designers are now faced with the challenge of balancing out their users' unpredictable privacy habits with regulations and guidelines regarding the personal data collected from them (Compañó & Lusoli, 2010).

When WhatsApp introduced its new privacy policy on the 4th of January 2021, users would have seen the changes appear as a pop-up message when they opened the application. This policy was introduced after WhatsApp's latest update, at the time, which required users to consent to have some of their data on the app linked to Facebook by no later than the 15th of May 2021 (Wijoyo et al., 2021). Because of this, WhatsApp received criticism from its users, with some considering closing their accounts and migrating to similar messenger apps like Telegram and Signal (Wijoyo et al., 2021). This decision, however, was not simple because WhatsApp has become a central point of communication for many users, with many activities, like sharing resources for online learning, being carried out on the platform during the pandemic.

The event has also been linked to a similar online privacy breach, namely the 2018 data breach with Facebook and Cambridge Analytica, which became one of the most publicised data breaches in recent years. This is because a swathe of individuals had data about them collected without their consent (Cadwalladr, 2018). The scale of data misuse, combined with the alleged claims of mass manipulation, provoked users and resulted in several protests which

called for people to close their Facebook accounts.

Since it entered the South African market, WhatsApp has been one of the key drivers in narrowing the divide between urban and rural areas in terms of internet engagement (Shambare, 2014). Overall, WhatsApp usage in South Africa increased by 40% during the lockdown in 2020, with more people using the app to stay connected with family members, friends, and colleagues (Parez, 2020). WhatsApp is no longer a simple instant messenger that can be used for social purposes; it has now become a central part of communication for many South Africans' lives as matters relating to school, work and business are now discussed more frequently over the app (Parez, 2020). Furthermore, WhatsApp was already a central platform of communication for South Africans before the pandemic. The circumstances brought about by the COVID-19 pandemic have only heightened WhatsApp's relevance in South African society as more aspects of people's lives, such as school and work, migrated online. Thus, because of their dependency on WhatsApp services, South African users received WhatsApp's proposed privacy policy with some resistance (Fiesler & Hallinan, 2018).

When WhatsApp was bought by Facebook in 2014, users were reassured that there were no plans to share their data with third parties or any other platform. However, the supposed change in stance shown by the introduction of the policy, Facebook, Cambridge Analytica, and similar privacy policy events have thus led to undermined trust amongst users and a perception that corporations are prioritising profit over user well-being (Bhattacharjee & Dana, 2017). WhatsApp also received criticism about its policy due to its bias. For instance, users in select European countries were exempt from the new policy. Meanwhile, users in other countries, particularly those in developing countries like India and South Africa, were not given the same option (Rajpurohit & Yadav, 2021), as refusing to accept the new terms meant that one's account would be fully discontinued. This limited users' autonomy regarding their decision over this policy. Incidents like these have also led to debates about the ethical standards of individuals' privacy and data security online as individuals and organisations deal with the increasing risk of online security threats and privacy in an increasingly digitised environment (Hinds et al., 2020). Therefore, it becomes essential to understand how social media users understand, perceive, and react to issues related to online privacy.

This study is an extension of a publication that explored how WhatsApp users based in South Africa perceived the January 2021 policy changes and how these views influenced their reactions to the policy (Mugadza & Mwalemba, 2022). This paper adds to the findings from the previous article and aims to explore the reasons behind users' actions on social media platforms. It does so by attempting to answer the following research question:

"How do WhatsApp users in South Africa view their role in ensuring their online privacy?"

The next section highlights several key research topics related to online privacy and social media. This is followed by a brief description of how the study was designed and conducted. The key insights found from the data are then presented and discussed, followed by a brief conclusion.

https://doi.org/10.18489/sacj.v35i2.17443

2 BACKGROUND

2.1 Social Media and Online Privacy

The use of social media can be empowering for users because SNSs seemingly offer their users creative control over the representations of their identities online (Bonanno, 2014). However, online users also generate large volumes of data, which companies rely on to improve their services for their customers and users. Hence, it is becoming a requirement for users to consent in some form to have their data shared with either the SNS service provider or another third party. This has implications for overall user privacy, autonomy, and empowerment (Beigi, 2018).

However, despite the concerns related to online privacy for users, Gibbs et al. (2010) argue that the benefits of having an online presence outweigh its risks. For instance, sharing one's data helps users and businesses maintain a relationship that can be used to personalise services based on an individual's preferences (Krasnova et al., 2010). This improves a business's operational efficiency while increasing user experience for its users or customers. There are, however, some risks that must be noted. As a result of the increased privacy concerns, people are becoming more concerned about their online presence and privacy and are particularly worried about the possible misuse of their data (Baruh et al., 2017). Consequently, users on the internet are becoming more vocal about their desire to have more control over their personal information online (Smit et al., 2014).

Having access to online privacy means that people have the freedom to determine when, how and to what extent information about them is shared with others (Smyth, 2014). As companies collect, use, and share the user data that is available online, people often lose control over their personal data. Hence, one of the most significant challenges faced by users who are active on the internet relates to their privacy online. This challenge is faced to the extent that managing and protecting one's online presence has become an essential part of daily life (Boerman et al., 2018).

2.2 Privacy Actives

A survey was conducted in 2019 by Cisco, an American technological conglomerate, to examine the actions and attitudes of adult online users regarding their data privacy. Results from the survey revealed that 32% of respondents identified themselves as individuals who care about their data security and privacy online (Redman & Waitman, 2020). Not only were these individuals willing to be proactive about ensuring their privacy, they had also already done so by switching companies or service providers over data-sharing policy disputes (Redman & Waitman, 2020). Individuals who fall into this category have since become known as "privacy actives", with 90% identified from the sample population believing that the way their data is used reflects how they will be treated. Based on these results, it was concluded that privacy actives are, therefore, unlikely to interact with a social media platform, application and (or) business if they do not trust how their data is going to be used (Redman & Waitman, 2020).

https://doi.org/10.18489/sacj.v35i2.17443

When asked whether they felt that they could protect their privacy online sufficiently, 52% of non-privacy actives agreed. Only a third (33%) of privacy actives agreed. The main concern raised by users was that it is not easy to know exactly how or when their data is or is going to be used. In other words, it is not easy to assess the trade-offs of using resources like social media applications upfront because one cannot know the purposes for which data will be used (Redman & Waitman, 2020). The survey results also revealed that privacy actives are the most likely to read privacy policies, where 83% actively do. However, the consensus within the sample population was that the language used in these policies could be unclear to the average person. Respondents also stated that having a detailed privacy policy or terms of use page is helpful, but taking the time to sort through it can be impractical due to its length and time constraints (Redman & Waitman, 2020).

2.3 Online Privacy vs. Convenience

Social media users and online consumers value their safety and want to feel safe (Goldstuck, 2012). Putting this into practice, however, is not something the average person finds practical. More than 80% of the individuals who participated in the Cisco survey felt that they could not protect their data and privacy online. This implies that users expect more of the responsibility for their data to be that of service providers like WhatsApp (Shillair et al., 2015).

Contrary to the results from the Cisco study (Redman & Waitman, 2020), prior research (Acquisti & Gross, 2006) showed that when forced to choose, users are more likely to opt for convenience over privacy. This behavioural pattern was observed even in users who ranked their privacy concerns higher than other societal concerns like politics (Schreiner & Hess, 2015). Additionally, results from a similar study (Stieger et al., 2013) revealed that users generally view the perceived benefits of using social media as a sufficient incentive to trade their privacy at the cost of their convenience.

A study was conducted by Schreiner and Hess (2015) that explored whether users would be willing to switch from one service to another over privacy concerns. It was found that dissatisfaction with privacy practices has a more substantial effect in influencing users to discontinue their use of a service over the attractiveness of a sound privacy policy (Schreiner & Hess, 2015). However, despite this observation, the authors also observed that it is more common for users to be unwilling to switch services. The authors attributed this to the high social cost and inconvenience that users would incur when restructuring their central networking platforms. In other words, though they express concern about their online privacy, users are unlikely to reflect their concerns in their actions (Acquisti & Gross, 2006).

There is, however, also some evidence to suggest that users can be willing to change their behaviour in some form after an online privacy breach, even if their behaviour does not reflect their concerns (Budak et al., 2021). This behaviour can be described as user resilience, where perceptions of past events influence how lenient users are when similar incidents occur in the future. This is because a user's online activity in various dimensions is supposedly affected by an online privacy violation event. The user's perceptions of the stressor (i.e., the social media

platform) are also likely to shift after the privacy breach has occurred (Budak et al., 2021).

When consumers (users) are affected by a stressor like an online privacy breach, they are likely to respond to this event with resistance. The level of resistance is likely to be influenced by their knowledge about, perceptions of, and attitudes towards a similar event. Their perceptions can be described as what users think about the event (Compañó & Lusoli, 2010). Their attitudes would refer to their beliefs about the event, and these are derived from the opinions (perceptions) that they would have formed about the event. Lastly, their behaviours can be described as how the users would react to events based on their opinions and beliefs. This can apply to how they would conduct themselves under normal circumstances or how they would respond to triggered events. This is described in the diagram in Figure 1 as the antecedents that influence an individual's level of resistance (Budak et al., 2021). Users' reactions to an online privacy breach can also be influenced by micro and macro-economic factors such as their educational and professional background, age, level of income, individual attitudes towards internet usage and cultural influences. The combined impact of all these factors will therefore influence how users are likely to respond to an online privacy violation or similar event (Budak et al., 2021).

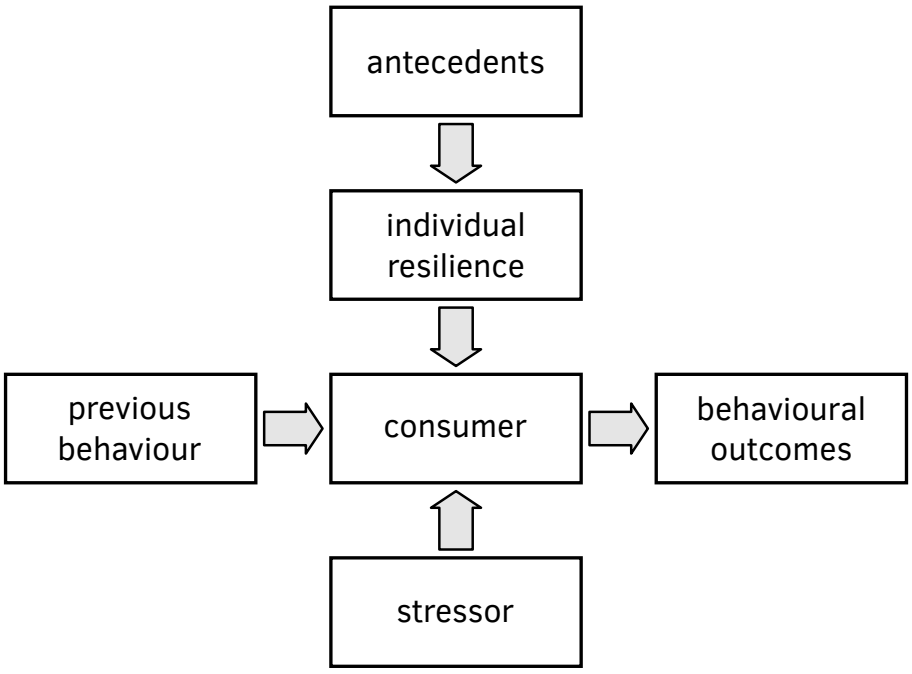


Figure 1: Consumer resilience to privacy violation online [a]

[a]Budak et al. (2021)

2.4 Privacy Responsibility – Consumer vs. Service Provider

Rather than placing the responsibility on a single party or stakeholder, Shillair et al. (2015) argue that the responsibility to protect user information online should be shared between users and service providers. Users should rather be encouraged to be more proactive about understanding how their data is used online, as they are currently settling for invasive or exploitative privacy practices at the expense of staying connected (Lipman, 2016). However, even though it seems users are at a disadvantage, Shillair et al. (2015) argue that users have the power to change a company's behaviour based on their reactions to new updates or the development of products that are put out into the market. Proof of this can be seen in WhatsApp's decision to extend its initial deadline for users to accept its January 2021 policy changes based on the criticism it received from the public (Wijoyo et al., 2021). This can be highlighted further by assessing an incident involving Instagram in 2012 (Lipman, 2016). When Instagram announced it was going to change its terms of service and allow users' photos to be sold on or via the platform, the issue gained widespread attention and media coverage. As a result of the public's reaction to the proposed changes, Instagram had to revise its new terms. Thus, there is some evidence to suggest that users do have some degree of influence over how companies handle their data on their behalf.

2.5 Privacy Responsibility – Service Provider vs. Government

While service providers are expected to take on the bulk of the responsibility with regard to online privacy, it seems that governments have more freedom to monitor social media data that is available to the public without being subjected to the same degree of regulation as service providers (Baruh et al., 2017). There is still a general expectation that businesses will be held accountable for non-compliance to privacy breaches. Meanwhile, when governments are found to have been abusing surveillance and privacy rights, this tends to be dismissed in favour of them maintaining national security online (Baloyi & Kotze, 2017). Some of the reasons governments would monitor their citizens include analysing social media data for the purposes of fighting crime or terrorism. However, as more people spend more time online and on social media platforms, Di Minin et al. (2021) argue that governments should also be subjected to the same regulations that are imposed on service providers. In summary, the responsibility of ensuring user privacy online should not be the responsibility of a solitary party. Instead, responsibility should be shared between all parties involved, namely the users, the service provider (companies) and governments (where applicable) (Di Minin et al., 2021).

A good example is Europe's enforcement of the GDPR in response to WhatsApp's January 2021 policy changes. The European Union (EU) regulates its citizens' data with strict guidelines set out in its GDPR (MyBroadband Staff Writer, 2021). Because of this, WhatsApp users in select European countries were given the option to opt out of the policy changes, while other users in several developing countries with similar protection policies and regulations were not given the same luxury (Kennedy & Thornberg, 2017). This inconsistent application of the policy highlights the fragmented nature of data protection laws worldwide and how

they are dictated by capital. Therefore, when examining the ideas proposed by Di Minin et al. (2021), it seems these cannot be applied universally. While some governments and similar governing bodies have the means to enact sufficient laws to protect their citizens, others still struggle to implement timely and effective laws to regulate the collection, processing and storage of citizens' data by powerful and omnipresent multinational companies.

2.6 International Surveillance Capitalism

Local companies are easier to regulate than multinational ones. Yet despite having some of the best protection policies in the world, policymakers in developing countries are restricted by the fact that several companies that are pivotal to a society's functioning in this digital era are international companies that are bound to their own rules. The most common social media applications used around the world are owned and controlled by a handful of American companies (Kwet, 2020). Furthermore, American companies also own and control some of the most important technological infrastructure required to use these platforms. Services like Netflix are beginning to dominate local television markets globally, while Google and Facebook dominate global advertising and distribution networks. This implies that a significant portion of the user data generated locally belongs to foreign countries.

Zuboff (2019) describes this phenomenon as surveillance capitalism, which is defined as an economic system that focuses on making a profit by collecting and processing personal data. More organisations are becoming dependent on user information for their analytics. User data on social media has thus become capitalised, with social media companies constantly looking to develop new ways of collecting more information from their users. Some of these new methods include competitions, reward programmes and loyalty cards (Kwet, 2020). WhatsApp and Facebook are based in the US, which means American laws are likely to be applied to the data collected from users in other countries. While some countries do have regulations to prevent their citizen's data from being stored outside of their borders, for the most part, the data centres and cloud facilities used to store social media data are based in the US.

This section highlighted that the issue of privacy is important and is becoming more prevalent in the era of social media and how the responsibility of enhancing and ensuring the public's privacy online is still a topic of discussion. There is the view that the responsibility should lie with the individual, while there are the opposing views that it should lie with the private sector or on governments and privacy regulators. Lastly, there is the view that the responsibility should be shared between the stakeholders involved. To get a full sense of how the issue of privacy unfolds, one needs to study all three stakeholders to understand how each of them looks at, understands and responds to the issues of privacy and their roles in this space. This study will target one stakeholder, namely the consumer, where the following sections will explore how WhatsApp users in South Africa view themselves as social media users in terms of online privacy.

3 RESEARCH DESIGN

The data for this study was collected through semi-structured interviews. The method used to identify the sample population was the cluster sampling method, where a group of people (adult WhatsApp users) based in a specific geographical location (South Africa) were targeted and approached in their capacity as individuals and asked to participate. Interviews were conducted until a point where the analysis of additional interviews generated little to no new codes or categories (Wolff et al., 2018, Ch.10). Table 1 lists respondents for this study according to age group and professional background.

Table 1: Sample Population Description

No	Reference	Age Group	Professional Background
1	User 1	20–30	Finance
2	User 2	20–30	Student – Technology
3	User 3	20–30	Student–Technology
4	User 4	20–30	Student–Engineering
5	User 5	20–30	Student–Technology
6	User 6	40–50	Telecommunications
7	User 7	40–50	Legal
8	User 8	50–60	Fin-Tech (Finance and Technology)
9	User 9	30–40	Digital Marketing
10	User 10	30–40	Public Health
11	User 11	30–40	Legal and Insurance
12	User 12	50–60	Technology
13	User 13	40–50	Retail and Technology
14	User 14	60+	Retired (worked in Education)

The data was analysed abductively using thematic analysis. This means researchers used concepts from some of the theories and frameworks from literature, such as Budak et al. (2021), Schreiner and Hess (2015) and Acquisti and Gross (2006), as a source of inspiration in identifying and interpreting the data to generate codes, categories, and themes (Kennedy & Thornberg, 2017). The emerging themes were used to group, make sense of, and describe respondents' influences and reactions to the policy changes. Figure 2 displays the evolution of the data analysis process.

4 RESULTS

The findings show that the most significant influences that affected how users reacted to the policy changes came from what they knew (awareness) and thought about the policy (perceptions). In addition to individual perceptions and general behavioural patterns regarding

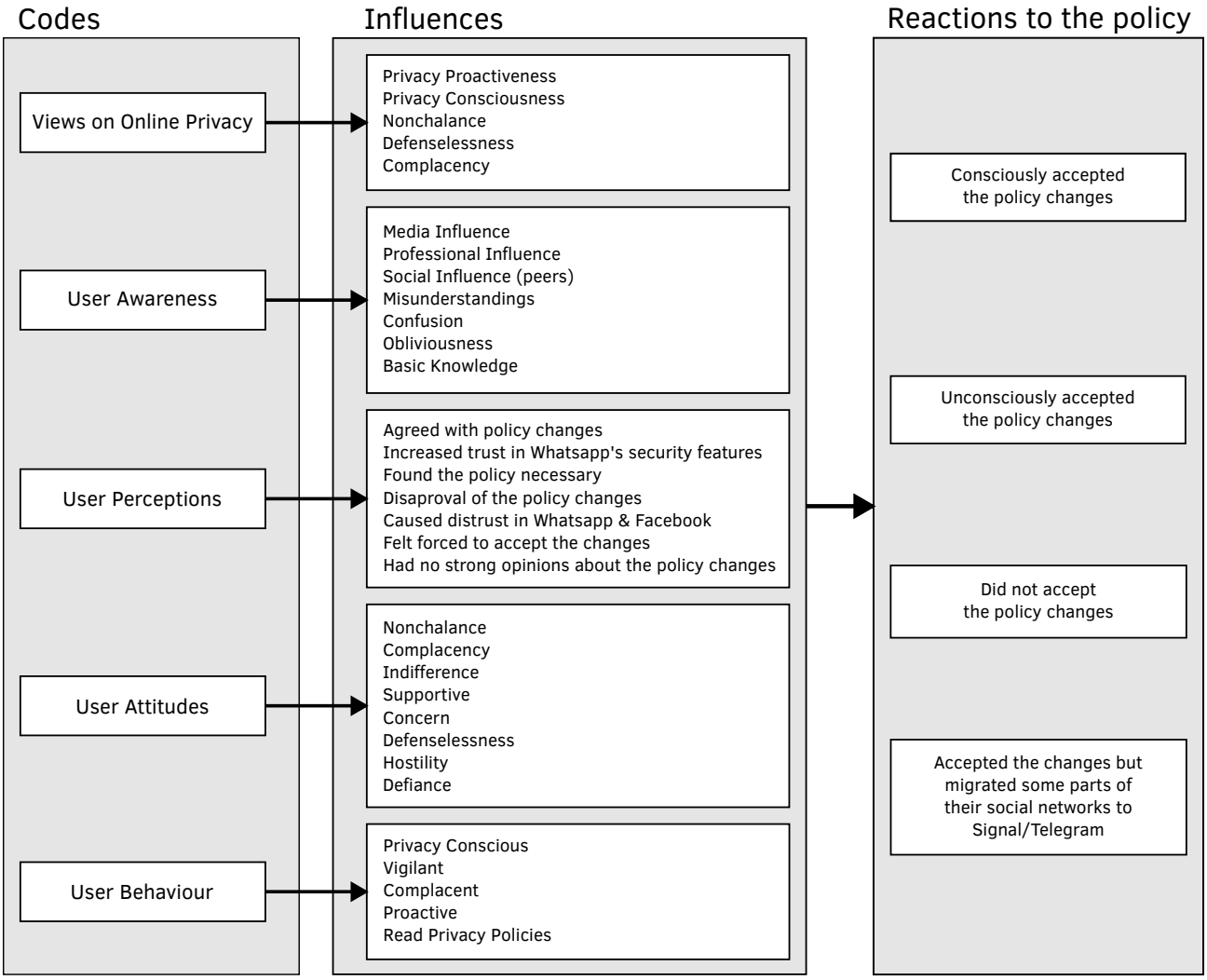


Figure 2: A data structure depicting the evolution of the thematic analysis from codes to key themes

online privacy, individualistic factors also influenced users' reactions to the policy changes. An example of this is seen with User 12, who is one of the older participants, and described themselves as a

"baby boomer (who) grew up with more face-to-face interactions",

or User 13, who understands the value of

"building a portfolio (of) consumer data"

due to their professional background in digital marketing. Both participants, however, disapproved of the policy changes, despite the contrasting individual factors described previously.

It can therefore be assumed that the unique combination of a user's knowledge about, perceptions of, and attitudes towards the policy, coupled with their general behaviour on social media, influenced their reactions to the policy changes to some extent. Further individual characteristics that influenced users' reactions are discussed below.

4.1 What did South African users know about the policy?

When examining how much users knew about the policy, it was found that users had some knowledge of the policy but not extensive knowledge of what it entailed or how it would impact them. In other words, users gave a spectrum of answers to describe the extent to which they knew about the policy, which ranged from obliviousness to basic knowledge to partial knowledge about the changes.

Some users were more aware of the policy because of their professional backgrounds. For example, people who had a legal or technological background appeared to understand the policy relatively more compared to users who did not

> *"… really know the details",* [User 10]

or who were only

> *"aware that there was a policy that was introduced"* [User 1]

from the media. None of the users fully understood what the policy entailed or how it would impact them and their usage of WhatsApp. None of the users had also taken the time to read the policy. What was also discovered from the results is that users are no longer as conscious of the policy compared to when it was introduced. As put by one of the users:

> *"I don't think about it on my day-to-day anymore. I'm only thinking about it now that you've mentioned it to me."* [User 4]

4.2 What did South African users think about the policy?

Perceptions about the policy changes differed, with users giving a range of responses. Some users objected to the policy changes and were not supportive of them, some users did not have any strong opinions about the changes, and some users were supportive of the policy changes.

In general, there were fewer users, such as those with a legal background, who supported the changes, with one user stating:

> *"I work in the legal department, and we actually have to know about these policies. The policy is a good thing because some companies will just go ahead and share your information with third parties without your consent. But at least with this policy, there is a preventative measure in place that provides safety for users and a means to take legal action."* [User 7]

https://doi.org/10.18489/sacj.v35i2.17443

Some users expressed that they were in favour of accepting the policy changes because their levels of trust with WhatsApp were higher compared to other instant messengers and social media platforms. In summary, users favouring the policy found it a

"necessary thing to have." [User 7]

When the policy was introduced, WhatsApp received widespread criticism from the public. However, users' perceptions of the policy changes were generally expressed as indifference, with users stating WhatsApp's accessibility and lack of alternatives for central communication as their main reasons for staying with the service. It was also deemed too much of an effort to restructure one's social networks by moving parts of it to Telegram and/or Signal. One user's response highlights this:

"If I don't use WhatsApp, what am I going to use because it's going to be difficult to move everyone I know over to Telegram." [User 2]

These feelings of nonchalance, complacency, indifference and even defencelessness towards the policy were still maintained even after users were made aware of how some users based in select European countries were exempted from accepting the policy changes. As seen with [User 8], even when given a choice, WhatsApp users based in South Africa were likely to have accepted the policy, but

"it would have been nicer if [they] had [been given] the choice"

to opt-out.

Lastly, this part of the results will look at the responses from the users who had not accepted the policy changes when they were interviewed. These users felt

"forced to agree to something [they were] not comfortable with" [User 12]

and decided that the cost of trading their privacy was a bigger loss. These users did not view WhatsApp as crucial to their networks in comparison to the other users in the sample, with one user stating,

"I'm not happy about it … I can live without it [WhatsApp]." [User 11]

4.3 How did South African users react to the policy changes?

In general, users accepted the policy, but there is evidence to suggest that users did so out of necessity and not choice, with one user stating:

"you have to accept it for you to continue having the platform." [User 10]

https://doi.org/10.18489/sacj.v35i2.17443

A few users consciously chose to accept the policy after taking the time to research its implications briefly. However, a significant portion of the sample that had accepted the policy had done so unconsciously. Not one user had taken the time to read the policy in-depth before accepting it, despite users from the sample identifying themselves as privacy-conscious individuals who are proactive about protecting their data.

All users, even the few who had not accepted the policy changes at the time, verified that they were still using WhatsApp due to how central it is to their communication with their social networks. Initially, users switched to another service when the policy was introduced, with the most popular choice for this sample being Telegram. A few other users opted for Signal. However, all users who switched stated that they were attracted back to WhatsApp due to its end-to-end encryption feature that they felt was lacking on other platforms.

5 DISCUSSION

As highlighted in the results, several factors influence how users respond to online privacy breaches or manage themselves online. Some factors can be generic, but the most significant influences come from a user's unique point of reference.

5.1 Online Privacy and User Behaviour

One theme that emerged from the data was that of online privacy. Users described themselves as privacy-conscious individuals who are vigilant when using social media. However, no users had taken the time to understand the policy in-depth when it was introduced. Furthermore, despite the spectrum of opinions regarding the policy changes, all users who were interviewed were still using WhatsApp at the time since it was the most convenient option for them.

This behavioural pattern matches the observations made by Schreiner and Hess (2015), where it was found that users would continue their use of an online service they are generally dissatisfied with due to the social opportunity costs and networking factors involved. Acquisti and Gross (2006) emphasise this point further. The authors argue that users' actions rarely affect their concerns in the event of a privacy breach. An example of this was observed with the Facebook and Cambridge Analytical data breach. Though there were several calls from privacy regulatory bodies and the media for users to close their Facebook accounts, it was found that users did not even take the time to alter their privacy settings, let alone discontinue their use of the app (Hinds et al., 2020). Similarly, the WhatsApp users participating in this study continued to use the app, despite their concerns.

This behaviour contrasts what would generally be expected from a privacy-conscious individual. Privacy-conscious individuals or 'privacy actives' are characterised by high standards and expectations of privacy policies. If privacy actives were dissatisfied with a service, they would not hesitate to discontinue using it (Redman & Waitman, 2020). The users who participated in this study identified themselves as privacy-conscious individuals who are attentive to how their data is used and shared online. However, their behaviour, as highlighted by the

evidence in the results and by multiple studies mentioned in the background, did not match their beliefs.

5.2 Macro and Micro-Economic Influences

The results from Section 4.3 also highlighted how a combination of influences unique to an individual influenced their reactions to the policy changes. This is supported by Budak et al. (2021), who state that when affected by an online privacy breach or a stressor, users' reactions are likely to be influenced by a combination of factors that would differ with each person. As observed with this group of users, the combination of what they knew and thought about the policy influenced their reactions. Using terminology provided by Budak et al. (2021), these influences would be described as macroeconomic factors. However, there were other influences, which were not as impactful as the previous two, that also influenced a user's reactions to the policy to some extent. These would be described as the micro-economic factors, which include a user's age, professional background, and general attitudes towards social media, WhatsApp and online privacy. Therefore, when putting the model developed by the authors in the context of this topic, the framework illustrated in Figure 3 would apply.

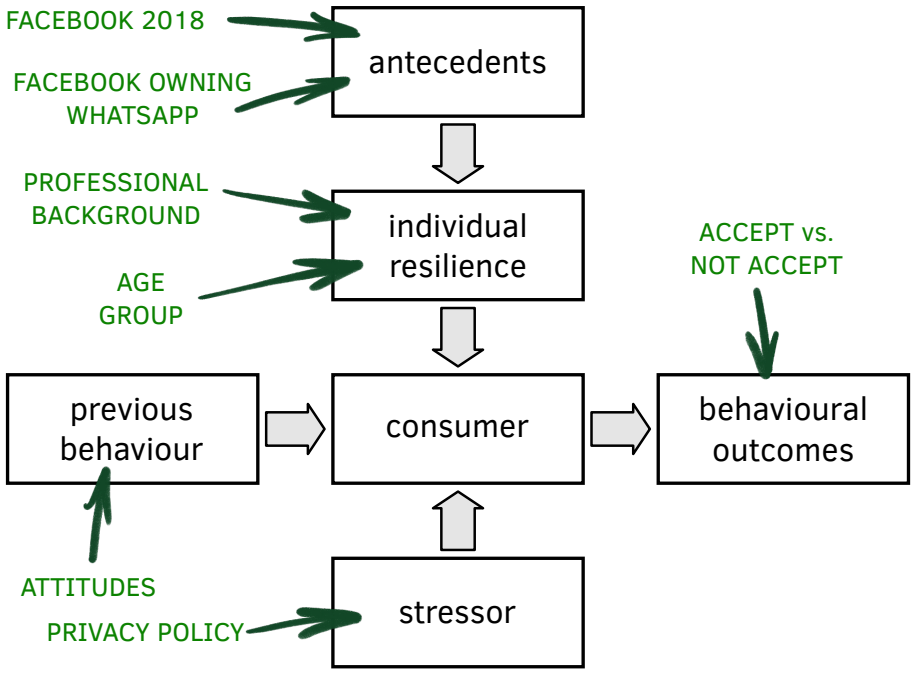


Figure 3: Updated research framework of consumer resilience to privacy violation online

The consumer becomes the user and the stressor becomes WhatsApp's January 2021 privacy policy. The antecedents that influenced the behavioural outcomes for this group of users

were WhatsApp's relationship with Facebook, with users linking the 2021 incident with the 2018 Facebook-Cambridge Analytica publicised event. Users who had strong, negative perceptions of this preceding event, and Facebook, disapproved of the policy changes and refused to accept them at the time of the interview. Further micro-economic factors such as an individual's professional background or age were also observed to have influenced a user's reactions to the policy changes. An example of this can be seen with users who have a background in the legal field. These users also had negative perceptions of Facebook but were supportive of the policy due to their understanding of how and why privacy legislation is designed and implemented. Therefore, as described in the results, the updated diagram in Figure 3 can be used along with the data structure presented in the results to gain further insight into this social phenomenon.

5.3 User Attitudes Towards Online Privacy

Users generally seemed indifferent, nonchalant, and complacent when asked about their opinions on the policy changes. These feelings and attitudes remained even when they were informed about how the policy was distributed unequally. This issue becomes more prevalent in developing countries like South Africa, where the most accessible social networking platforms are developed and owned by large multinational corporations. The issue observed is that the regulatory bodies in said developing countries struggle to enforce their legislature and regulations on these corporations to protect their citizens. This leaves users in these economies vulnerable to potential exploitation from service providers. As a consequence, noting that the options they can use to protect themselves are limited, coupled with the fact that their regulatory bodies do not have the requisite influence to deter these corporations, social media users in developing counties begin to develop attitudes of defencelessness, complacency, and indifference in events like this despite being dissatisfied with the situation.

Because of the pervasiveness of social media, the issue of responsibility in enhancing privacy for users online is still a topic of discussion. As seen through the Cisco study (Redman & Waitman, 2020), users would like to be more proactive about ensuring their privacy online but feel that their autonomy is limited. Hence, users place the expectation of ensuring their privacy on the private sector and service providers like WhatsApp. Where the private sector fails, the expectation is then placed on governments and policy regulatory bodies to intervene on behalf of the consumer (Ahad & Lim, 2014).

6 CONCLUSION AND RECOMMENDATIONS

This study explored how consumers view and perceive their role in ensuring online privacy. Based on the findings and discussion, we see that users have little influence in safeguarding their online privacy. This is because they are often put in a position where they must choose convenience at the expense of their privacy to maintain using their social networks, despite

this going against their best interests. An example of this can be seen in how WhatsApp users based in South Africa responded to the January 2021 policy changes.

Despite the overall criticism WhatsApp received when the policy was introduced, users generally had neutral perceptions about the policy and accepted the terms without much resistance or conscious effort. WhatsApp was already a central point of communication for people in South Africa before the pandemic, as work, school and personal networks were all managed on the platform. Users thus accepted the policy out of necessity because the opportunity costs they would have incurred to restructure their social networks seemed too significant. The disparity in regulatory enforcement between countries has also left users to act on their own, as most developing countries do not have privacy laws that are strong enough to protect their users.

It is recommended that researchers use this study as grounds for further large-scale research to observe and understand how the other two stakeholders (corporations and governing bodies) perceive and understand their roles in the digital space. This study has provided some insight into why users tend to behave the way they do online. However, further research is required to develop an in-depth understanding of how privacy issues unfold between all three stakeholders.

References

Abbas Naqvi, M. H., Jiang, Y., Miao, M., & Naqvi, M. H. (2020). The effect of social influence, trust, and entertainment value on social media use: Evidence from Pakistan (Y. J. Wu, Ed.). *Cogent Business & Management*, *7*(1), 1723825. https://doi.org/10.1080/23311975.2020.1723825

Acquisti, A., & Gross, R. (2006). Imagined communities: Awareness, information sharing, and privacy on the Facebook. In *Lecture notes in Computer Science* (pp. 36–58). Berlin Heidelberg, Springer. https://doi.org/10.1007/11957454_3

Ahad, A. D., & Lim, S. M. A. (2014). Convenience or Nuisance?: The 'WhatsApp' Dilemma. *Procedia – Social and Behavioral Sciences*, *155*, 189–196. https://doi.org/10.1016/j.sbspro.2014.10.278

Baloyi, N., & Kotze, P. (2017). Are organisations in South Africa ready to comply with personal data protection or privacy legislation and regulations? *2017 IST-Africa Week Conference (IST-Africa)*, 1–11. https://doi.org/10.23919/istafrica.2017.8102340

Baruh, L., Secinti, E., & Cemalcilar, Z. (2017). Online privacy concerns and privacy management: A meta-analytical review: Privacy concerns meta-analysis. *Journal of Communication*, *67*(1), 26–53. https://doi.org/10.1111/jcom.12276

Beigi, G. (2018). Social media and user privacy. *2018 International Conference on Social Computing, Behavioral-Cultural Modeling, & Prediction and Behavior Representation in Modeling and Simulation*, *abs/1806.09786*. http://arxiv.org/abs/1806.09786

Bhattacharjee, A., & Dana, J. (2017). People think corporations can't do good and make money. Can companies prove them wrong? *Harvard Business Review, November 28, 2017*. https://www.brandreality.se/wp4/wp-content/uploads/2018/11/HBR.pdf

Boerman, S. C., Kruikemeier, S., & Zuiderveen Borgesius, F. J. (2018). Exploring motivations for online privacy protection behavior: Insights from panel data. *Communication Research*, *48*(7), 953–977. https://doi.org/10.1177/0093650218800915

Bonanno, E. R. (2014). The social media paradox: An examination of the illusion versus the reality of social media. *Sociological Imagination: Western's Undergraduate Sociology Student Journal*, *3*(1), 1–4. https://ojs.lib.uwo.ca/index.php/si/article/download/5271/4416/

Budak, J., Rajh, E., Slijepčević, S., & Škrinjarić, B. (2021). Conceptual research framework of consumer resilience to privacy violation online. *Sustainability*, *13*(3), 1238. https://doi.org/10.3390/su13031238

Cadwalladr, C. (2018). Facebook suspends data firm hired by Vote Leave over alleged Cambridge Analytica ties [7 April 2018]. *The Guardian*. https://www.theguardian.com/us-news/2018/apr/06/facebook-suspends-aggregate-iq-cambridge-analytica-vote-leave-brexit

Church, K., & de Oliveira, R. (2013). What's up with WhatsApp?: Comparing mobile instant messaging behaviors with traditional SMS. *Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services*, 352–361. https://doi.org/10.1145/2493190.2493225

Compañó, R., & Lusoli, W. (2010). The policy maker's anguish: Regulating personal data behaviour between paradoxes and dilemmas. In *Economics of information security and privacy* (pp. 169–185). Springer US. https://doi.org/10.1007/978-1-4419-6967-5

Di Minin, E., Fink, C., Hausmann, A., Kremer, J., & Kulkarni, R. (2021). How to address data privacy concerns when using social media data in conservation science. *Conservation Biology*, *35*(2), 437–446. https://doi.org/10.1111/cobi.13708

Duggan, M., Ellison, N. B., Lampe, C., Lenhart, A., & Madden, M. (2015). Pew research center: Social media update 2014. https://www.pewresearch.org/internet/2015/01/09/social-media-update-2014/

Fiesler, C., & Hallinan, B. (2018). "We are the product": Public reactions to online data sharing and privacy controversies in the media. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3173574.3173627

Gibbs, J. L., Ellison, N. B., & Lai, C. (2010). First comes love, then comes Google: An investigation of uncertainty reduction strategies and self-disclosure in online dating. *Communication Research*, *38*(1), 70–100. https://doi.org/10.1177/0093650210377091

Goldstuck, A. (2012). Internet matters: The quiet engine of the South African economy. *World Wide Worx*, *236*. https://hsf.org.za/publications/focus/focus-66/AGoldstuck.pdf

Hashimzade, N., Myles, G. D., Page, F., & Rablen, M. D. (2014). Social networks and occupational choice: The endogenous formation of attitudes and beliefs about tax compliance.

Journal of Economic Psychology, *40*, 134–146. https://doi.org/10.1016/j.joep.2012.09.002

Hinds, J., Williams, E. J., & Joinson, A. N. (2020). "It wouldn't happen to me": Privacy concerns and perspectives following the Cambridge Analytica scandal. *International Journal of Human-Computer Studies*, *143*, 102498. https://doi.org/10.1016/j.ijhcs.2020.102498

Kennedy, B. L., & Thornberg, R. (2017). Deduction, induction, and abduction. In U. Flick (Ed.), *The SAGE handbook of qualitative data collection*. SAGE Publications Ltd. https://methods.sagepub.com/book/the-sage-handbook-of-qualitative-data-collection

Krasnova, H., Spiekermann, S., Koroleva, K., & Hildebrand, T. (2010). Online social networks: why we disclose. *Journal of Information Technology*, *25*(2), 109–125. https://doi.org/10.1057/jit.2010.6

Kwet, M. (2020). Surveillance in South Africa: From skin branding to digital colonialism. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.3677168

Lipman, R. (2016). Online privacy and the invisible market for our data. *Network Security*, *2004*, 18–19. https://doi.org/10.1016/S1353-4858(04)00120-5

Montag, C., Błaszkiewicz, K., Sariyska, R., Lachmann, B., Andone, I., Trendafilov, B., Eibes, M., & Markowetz, A. (2015). Smartphone usage in the 21st century: Who is active on WhatsApp? *BMC Research Notes*, *8*(1). https://doi.org/10.1186/s13104-015-1280-z

Mugadza, K., & Mwalemba, G. (2022). Online platform privacy policies: South frican Whatsapp users' perceptions and reactions to the January 2021 changes. In A. Gerber (Ed.), *Proceedings of 43rd conference of the south african institute of computer scientists and information technologists* (pp. 214–230, Vol. 85). EasyChair. https://doi.org/10.29007/m9d5

MyBroadband Staff Writer. (2021). WhatsApp privacy concerns in South Africa explained. https://mybroadband.co.za/news/security/384886-whatsapp-privacy-concerns-in-south-africa-explained.html

Nobre, G. P., Ferreira, C. H., & Almeida, J. M. (2022). A hierarchical network-oriented analysis of user participation in misinformation spread on WhatsApp. *Information Processing & Management*, *59*(1), 102757. https://doi.org/10.1016/j.ipm.2021.102757

Parez, S. (2020). Whatsapp has seen a 40% increase in usage due to COVID-19 pandemic [TechCrunch]. https://techcrunch.com/2020/03/26/report-whatsapp-has-seen-a-40-increase-in-usage-due-to-covid-19-pandemic/

Perrin, A. (2015). Social media usage: 2005-2015. https://www.pewresearch.org/internet/2015/10/08/social-networking-usage-2005-2015/

Rajpurohit, G. S., & Yadav, R. K. (2021). A socio-legal analysis of Whatsapp privacy policy 2021 in India: A contemporary study. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.3850579

Redman, T. C., & Waitman, R. M. (2020). Do you care about privacy as much as your customers do? https://hbr.org/2020/01/do-you-care-about-privacy-as-much-as-your-customers-do

Schreiner, M., & Hess, T. (2015). Examining the role of privacy in virtual migration: The case of WhatsApp and Threema. *AMCIS 2015 Proceedings*. https://aisel.aisnet.org/amcis2015/ISSecurity/GeneralPresentations/33

Shambare, R. (2014). The adoption of Whatsapp: Breaking the vicious cycle of technological poverty in South Africa. *Journal of Economics and Behavioral Studies*, *6*(7), 542–550. https://doi.org/10.22610/jebs.v6i7.515

Shillair, R., Cotten, S. R., Tsai, H. S., Alhabash, S., LaRose, R., & Rifon, N. J. (2015). Online safety begins with you and me: Convincing internet users to protect themselves. *Computers in Human Behavior*, *48*, 199–207. https://doi.org/10.1016/j.chb.2015.01.046

Smit, E. G., Van Noort, G., & Voorveld, H. A. (2014). Understanding online behavioural advertising: User knowledge, privacy concerns and online coping behaviour in Europe. *Computers in Human Behavior*, *32*, 15–22. https://doi.org/10.1016/j.chb.2013.11.008

Smyth, B. (2014). *Forget Me Do: Empowering user privacy on social network sites* (tech. rep. No. 2014/10). Forget Me Do Limited. https://publications.bensmyth.com/2014-privacy-on-social-network-sites/

Stieger, S., Burger, C., Bohn, M., & Voracek, M. (2013). Who commits virtual identity suicide? Differences in privacy concerns, internet addiction, and personality between Facebook users and quitters. *Cyberpsychology, Behavior, and Social Networking*, *16*(9), 629–634. https://doi.org/10.1089/cyber.2012.0323

Wijoyo, H., Limakrisna, N., & Suryanti, S. (2021). The effect of renewal privacy policy Whatsapp to customer behavior. *Insight Management Journal*, *1*(2), 26–31. http://repository.upi-yai.ac.id/3136/

Wolff, B., Mahoney, F., Lohiniva, A. L., & Corkum, M. (2018). Collecting and analyzing qualitative data. In S. A. Rasmussen & R. A. Goodman (Eds.), *The CDC field epidemiology manual*. https://www.cdc.gov/eis/field-epi-manual/chapters/Qualitative-Data.html

Zuboff, S. (2019). Surveillance capitalism and the challenge of collective action. *New Labor Forum*, *28*(1), 10–29. https://doi.org/10.1177/1095796018819461

SACJ 35(2) December 2023
Research Article

Challenges of Implementing Enterprise Resource Planning and the Role of Knowledge Management: Evidence from the National Youth Development Agency

Nompumelelo Zuma, Ntandoyenkosi Sibindi

University of the Western Cape, Robert Sobukwe Rd, Bellville, Cape Town, South Africa

ABSTRACT

Using the National Youth Development Agency (NYDA) as a case study, this paper considers the challenges of implementing enterprise resource planning (ERP). Data was collected from management and employees using both qualitative and quantitative research techniques. The study established challenges beyond the technical issues, these included: misalignment of the system to the organisation processes, product quality and unavailability of the system's helpdesk, lack of top management support, and lack of pilot testing, insufficient end-user training, resistance to change management, lack of processes integration, poor technology planning and security and risk matters. Furthermore, the management process that resonates on knowledge transfer, knowledge management, and change management poses a complex challenge in the implementation of ERP. The study recommends the alignment of the user environment, effective change management, and knowledge strategies that are essential to drive ERP. It is also recommended to close the gap between what ERP offers and what end users want and can do.

Keywords Enterprise resource planning, ERP implementation, public sector organisations, ERP challenges, knowledge transfer, knowledge management, change management

Categories • **Information systems** ∼ **Information systems applications, Enterprise information systems, Enterprise resource planning**

Email
Nompumelelo Zuma – 4177460@myuwc.ac.za,
Ntandoyenkosi Sibindi – nsibindi@uwc.ac.za (CORRESPONDING)

Article history
Received: 9 September 2023
Accepted: 13 November 2023
Online: 14 December 2023

1 INTRODUCTION

Organisations are investing significant capital in information systems that facilitate remote work and cloud networking. Organisations prefer systems that offer all the tools required for information resource management. Of the available systems, enterprise resource planning

Zuma, N., and Sibindi, N. (2023). Challenges of Implementing Enterprise Resource Planning and the Role of Knowledge Management: Evidence from the National Youth Development Agency. *South African Computer Journal* 35(2), 97–118. https://doi.org/10.18489/sacj.v35i2.17410

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

(ERP) systems are the most implemented system due to their advanced features that surpass those of other systems in the market (Alieva & Haartman, 2021). An organisation must leverage its rich tapestry of knowledge to better implement ERP systems. Knowledge management (KM) is the backbone of modern technology adoption, providing managers with the information necessary to customise ERP systems to meet organisational needs (Alieva & Haartman, 2021).

As information technology (IT) has become one of the foremost cornerstones of an enterprise's ability to successfully compete within the global marketplace nowadays, no organisation can fully function without taking technology needs into consideration (Kiran & Reddy, 2019). In the early 90s, companies implemented customer relations management (CRM) and business process re-engineering (BPR) as the main software that could hold all the functions of organisations and keep them afloat (Sheik & Sulphey, 2020). With ever-changing technological innovations, one system does not have a long life-expectancy in the technological environment (Markus & Tanis, 2000). As a result of its ability to recognise the year 2000, ERP software inched ahead of other software in terms of popularity among organisations (Markus & Tanis, 2000).

To automate its business processes and improve its operational efficiency and effectiveness, the National Youth Development Agency (NYDA) deemed ERP as appropriate for its operations. All the business processes within the organisation were running manually and separately from each other, each with its policies. The flow of information was very slow and collecting in-time information was problematic as information was either with a certain person or locked somewhere. Such a situation was the major cause for delay in decision-making and further implementation. Even solving complaints was a problem, and therefore the organisation's effectiveness was tarnished. In 2018, through a vendor, NYDA developed and designed an ERP system that was tailor-made to meet the needs of the organisation instead of buying an off-the-shelf ERP solution.

The adoption of technology by any organisation requires a management process that calls for effective knowledge management (KM), knowledge transfer, and change management (Zuma & Sibindi, 2023). This paper presents ERP, its uses, and the risks associated with ERP, and before discussing the technology acceptance models, the research methodology is presented followed by the findings, discussions, recommendations, and conclusion.

2 ERP AND ITS BENEFITS

Enterprise resource planning, referred to by its industry acronym, ERP, refers to the automation and integration of an organisation's core business and storing it in a cloud network where anyone who has access can use it (Alieva & Haartman, 2021). Kang et al. (2020) explained that any organisation that prefers to adopt ERP systems aims to accelerate productivity, efficiency, and organisational competitiveness to realise a competitive edge.

Kang et al. (2020) defined ERP systems as software that allows information to be communicated more effectively and consistently within the organisation, while being kept in a secured

cloud and accessible by all the users, via a shared database. ERP guarantees a shorter communication time between departments and quickens the time required to complete business transactions (cycle time) and delivery is shortened further, making it quick to meet customer needs while providing easier access to information by all departments and sub-departments within an organisation, and reducing redundancy (Kang et al., 2020). In this highly automated, IT-led business environment, companies are forced to stay up-to-date with innovative technologies to remain competitive (Alieva & Haartman, 2021). Innovative technology adaptation by organisations puts them in a competitive position, allowing them to gain a reasonable market share compared to their competitors (Sheik & Sulphey, 2020).

ERP systems provide significant advantages to companies who adopt them as they integrate business applications using real-time information and provide cloud storage ready for retrieval of that information. Businesses stand to gain from cloud computing services (de Oliveira & de Almeida, 2019), as they can get access to infrastructure and software at affordable rates. cloud computing offers businesses the opportunity to improve their IT capabilities in a way that they previously could not (Paksoy et al., 2021). ERP systems provide the means for management to respond to the increasing business needs in effective and efficient ways better than any previously implemented IT solution (Wang et al., 2021). The successful adoption of the 4th industrial revolution relies on the commitment of governments, businesses, and citizens to support transformation and be ready to adapt to change, have the willingness to learn, and have enough resources to do so.

2.1 Features of ERP

Business intelligence (BI) is software that can transform raw data into meaningful metrics reflective of historical, current, and predictive business operations and performance (Secundo et al., 2023). In other words, BI is a user-oriented process of extracting, exploring, interpreting, and analysing data, which managers use to expedite and rationalise the decision-making process (de Oliveira & de Almeida, 2019). Organisations need BI for real-time information to help them make intelligent decisions in the short and long term (Ain et al., 2019). Organisations using BI have the advantage of better analysis and real-time decision-making with the provision of robust analytical capabilities, such as access to reports and dashboard management and advanced analytical features that allow users to view data from diverse sources.

Data aggregation and analysis ERP systems are known for their ability to generate enormous volumes of data in a short period, saving an organisation in finance (Chaushi et al., 2018). Integration of ERP with BI enables businesses to draw in-depth insights from their data directly within their ERP platforms. Businesses need data that is gathered and represented in a summarised form, for purposes including statistical analysis. This allows the organisation to track its performance against the annual targets and minimise performance problems.

https://doi.org/10.18489/sacj.v35i2.17410

Customisation is when an organisation makes code modifications to the software to better fit the needs of the organisation's processes and product delivery. This cannot be done virtually and needs human labour while the margin for error is virtually non-existent (Wang et al., 2021). customisation must be done correctly for the ERP system to benefit the organisation. Each organisation team generates the reports and dashboards needed to meet their sub-division targets and objectives while working towards a common organisational goal when the BI-ERP systems are tailor-made and well-integrated to incorporate the needs of the organisation.

Predictive capabilities The ERP is enabled to detect and react to both risks and opportunities for the future by smartly combining real-time data, as well as planning, prediction, and simulation data (Gupta et al., 2019). These predictive capabilities help to make processes more efficient and intelligent and offer new opportunities for the organisation in the future. COVID-19, as a global pandemic, has helped organisations steer their enterprise through rough waters and has given them the agility to react to ever-changing environments quickly.

e-Commerce features ERP platforms have pre-built functionality which makes them very worth having as an organisation but should not be the end-all-be-all software search. A vendor should always provide a buying organisation with easy integration with e-commerce functionality through add-ons or modules that speak to what the organisation does (Kujala & Halonen, 2019). This pre-built functionality allows for repetitiveness; data integrity; elimination of productivity gaps; efficiency; developed business growth; better customer support and service; and improved brand loyalty.

Customer relationship management (CRM) CRM-infused ERP software and tools are mostly needed to make vital information available across an entire organisation (Perez-Estebanez et al., 2017). CRM enables users to see the entire organisation's data across departments through the common dashboard. Millions of clients' information is stored and accessed by authorised access while it keeps a record of who last did what and when on the system.

Improves security and manages cyber risks The rapid development and application of new digital technologies and organisations working on cloud networks have opened new opportunities for more efficient management of technology and organisations' processes, which has led to a significant increase in security threats, phishing, fraud, and increasing the vulnerability of businesses and organisations to cyber criminals (Rani et al., 2021). ERP systems provide security as an important aspect of the entire system that is properly maintained to achieve reliable and secure operation of the entire system, because if corrupted, the whole organisation will suffer the consequences.

Add-on facilities A tailor-made ERP system provides add-on modules that can be purchased from different vendors, which is considered a competitive approach (Ruivo et al., 2020). These add-ons include invoice automation facilities, supply chain management, inventory

management, and human resources management, which make it easier for the organisation to stay paperless and easily operational.

2.2 ERP Implementation: Management issues

Knowledge management (KM) refers to the processes and activities that support an organisation in generating, acquiring, discovering, organising, using, and disseminating knowledge among its employees (Perez-Estebanez et al., 2017). This knowledge is transformed into information and experience which can be applied in decision-making, problem-solving, learning, and strategic planning (Abusweilem & Abualous, 2019; Oliveira et al., 2020).

Effective management processes of both tangible and intangible assets are crucial for organisations (Kianto et al., 2020). To achieve this, the integration of KM and ERP is essential. However, the explicit theoretical perspectives on the relationship between KM and ERP have not been well-established in previous studies. Although some studies have highlighted the relationship between KM and ERP (Andreeva & Kianto, 2012), they have mainly focused on identifying the successes and failures of such integration.

Effective use of knowledge management in ERP implementation accelerates the process while producing positive effects on ERP usage for organisations to enhance their implementation. ERP implementation in existing literature identifies change management as the critical success factor. Organisations must collaborate with end-users to avoid resistance to ERP implementation during the final stage of implementation (Beydoun et al., 2019; Holland & Light, 1999). It is important to explain the benefits of ERP implementation compared to the traditional system to employees. Effective change management is a second necessary factor as it can determine the success or failure of ERP implementation, depending on employee acceptance (Albarghouthi et al., 2020; Azima et al., 2019). Thus, organisations should manage change effectively and inform employees of any changes in advance during ERP implementation. change management is, therefore, an essential aspect of ERP implementation.

Effective knowledge transfer is another essential aspect for the successful implementation of ERP. An organisation needs to share knowledge with vendors and allow end-users to have input in the implementation of the system. By doing this, an organisation can reduce the costs associated with correcting mistakes caused by the lack of information transfer and improve clients' service delivery while gaining competitive business advantages through effective product and process innovation (Markus et al., 2000). Thorough awareness and identification of the knowledge required for any implementation are at the core of ERP implementation. ERP implementation should be able to integrate an organisation's information regarding its resources to create interactions with business partners and enhance operational performance to enable an organisation to gain a competitive advantage in the market.

https://doi.org/10.18489/sacj.v35i2.17410

3 TECHNOLOGY ACCEPTANCE MODELS

How new technology is accepted by the members of the organisation and the organisation as a whole has received attention from both management and IT scholars. Three categories of models attempt to explain the behaviours of technology acceptance by organisations and individuals. These categories emerge from psychology, social science, and IT.

From the psychology strand, three models emerge: the Theory of Reasoned Action (TRA), the Theory of Planned Behaviour (TPB), and Decomposed Theory of Planned Behaviour (DTPB). Ajzen (1991) advanced the TRA model to explain how attitude and subjective norm influence the behaviour of individuals towards technology. The TPB model extended the TRA model by adding the perceived behavioural control construct to explain intention and acceptance behaviour (Ajzen, 1991). DTPB decomposes the TPB to explain acceptance behaviour through multi-dimensional belief constructs (Taylor & Todd, 1995). Drawing from the Innovation Diffusion Theory (IDT) concept, the DTPB model includes relative advantage, compatibility, and complexity variables to explain the behaviour (Taylor & Todd, 1995). The psychology models attempt to predate and explain the behaviour of technology acceptance.

Modelled around social behaviour, the sociology models are anchored on motivation. Self-Determination Theory (SDT) (Deci & Ryan, 1985) has been used to explain extrinsic and intrinsic motives for using technology (Davis et al., 1992). The Social Learning Theory (SLT) advanced by Bandura (1989) places importance on social influence and its effect on external and internal social reinforcement. According to the model, the previous experience of an individual informs behaviour change. The SLT model has been used to measure self-efficacy and expectations in IT (Compeau et al., 1999). Weeger and Gewald (2013) used SLT to explain IT anxiety and emotional reactions. The IT-centred models such as the Technology Acceptance Model (TAM) measure technology variables such as perceived usefulness and perceived ease of use (Davis, 1986). This study is grounded on the combination of constructs advanced by the models that emerge from the three fields identified.

4 RESEARCH METHODS

This study is based on a single case study in a public sector organisation, the NYDA.

This methodology was adopted to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context. The case study was incorporated into mixed-method research using both qualitative and quantitative data collection instruments to seek a more complete understanding. The case study is an established research design that is used extensively in a wide variety of disciplines, particularly in the social sciences (Aberdeen, 2013). Despite various studies that have been conducted to explain different factors affecting ERP implementation, there is a lack of research conducted in public sector organisations in South Africa. Semi-structured interviews of the top management and a survey were used for data collection from the end-users who are the junior staff members and the implementors of the products and services at NYDA.

https://doi.org/10.18489/sacj.v35i2.17410

4.1 Population and Sample

NYDA has several branches throughout South Africa, employing over 460 employees and 24 managers and is currently launching the ERP system throughout its different branches across the country. The organisation has 44 districts and centre offices in all South African provinces with its head office in Gauteng province. The ERP implementation is in the developed stage with ongoing organisation-wide training since it has gone live. Several individual purposeful interviews were carried out with the organisation's senior employees and surveys were used to collect data from the junior employees. All the participants had been through the training and were impacted by the ERP implementation process. For employees, participants were randomly selected as their roles and standing are more-or-less the same (quantitative). As for managers, a convenient sampling technique was used depending on their availability for interviews.

4.2 Instruments

The measurement items for the quantitative instrument were drawn from studies that have considered the challenges of ERP. Appendix A summarises the instrument items and their sources and gives examples of questions. For the qualitative interview guide, the study informed by the literature grouped the interview into three segments as follows: ERP package knowledge, ERP training, and outputs and expectations. Appendix B summarises the interview guide.

4.3 Response Rate

Out of the population of 24 selected for qualitative data collection, data saturation was reached after the 14th participant, resulting in a 50% response rate. According to Aberdeen (2013), reaching saturation after interviewing 12 participants is acceptable, especially for studies aiming to understand commonalities within a homogeneous group. Saunders et al. (2023) further suggest that researchers should continue collecting qualitative data until data saturation is reached. In this study, 14 semi-structured one-on-one interviews were conducted, and it was concluded that data saturation was reached after 12 interviews. However, questioning continued until the adequacy of the information obtained was verified.

The quantitative data was collected by administering survey questionnaires to junior staff members of the NYDA, with a target population of one hundred and ninety-eight (198). One hundred and fifteen (115) staff members responded to the survey, comprising twenty-one (21) coordinators, sixty-six (66) officers, twenty-five (25) administrators, and three (3) general workers, all of whom play a direct role in the utilisation of ERP to implement the organisation's products. The survey questionnaires were administered seven months after the initial invitation, and the response rate was 58% of the sample. Mugenda and Mugenda (1999) recommended that response rates above 50% are adequate for surveys and can be considered representative of the population. Therefore, the response rate of this study is sufficient to use the collected data for generalisation and concluding.

https://doi.org/10.18489/sacj.v35i2.17410

5 THE CHALLENGES

The study established that ERP end-users experienced several challenges throughout the implementation process, leading to a delayed and not fully functional system. Most of the issues were experienced by the users during the "go live" period set by the vendor and the management of the organisation. The training is amongst the challenges that were experienced leading to the ERP system's initial "go live" date being delayed. Most challenges identified by the end-users were being addressed while the system was meant to "go live". The challenges experienced are comprehensively explained in the section below.

Misalignment of the system to the organisation processes

The vendor's misunderstanding of the requirements of the ERP in the organisation may have a high risk in the business performance post-implementation (Gavidia et al., 2021). This was the case with the NYDA ERP implementation; there was a failure to manage change properly as employees were not prepared for the changes that the system would bring. The vendor, when asked to add some tasks to the system, wanted to add more costs which led to time overruns as well as the lack of an effective methodology. The organisation must redesign its traditional processes to fit to purchase of an ERP system for the smooth running of the newly implemented system (Huang & Yokota, 2018). With organisations purchasing the changed off-shelf software, it is not easy to convert it into a tailor-made ERP system to fit current processes, and that is a costly and time-consuming venture most vendors are not prepared for. This has been the biggest ERP implementation risk for the NYDA.

Product quality and unavailability of the system's helpdesk

Irrespective of the ERP systems becoming increasingly similar in functionality and more relevant to most organisations' operations, their quality and ease of implementation differ (Jenab et al., 2019). The stability and functionality of the new system may not be guaranteed in quality and implementation ease. The NYDA's case portrayed the same challenge. The system developers were unable to produce a quality and easy-to-use system, so the postponement of the "go live" took place on more than one occasion. This was due to the system processes skipping most of the vital interactions in the product being worked at and skipping some employees' roles, which could have led to incomplete product delivery or product output. While the employees were noticing this, there was a lack of a helpdesk to guide them and solve the technical problems that were arising.

Lack of top management support and pilot testing

The top management's availability to render support to the end-users is crucial for accomplishing any project objectives in an organisation. The senior managers of the NYDA were very much available to sponsor the project but failed to share and transfer information for a

better understanding of the new system for the users. The organisation did not pilot test the system which could have helped spot the deficiencies earlier before the whole organisation went live. The other option that could have worked was for the NYDA to nominate super users who would be trained to train other users for the ease of transition into the new system; unfortunately, this did not happen either. Allocation of sufficient financial and human resources is needed to fully support the ERP implementation to prevent ineffective knowledge transfer and vendors rushing the implementation. The top management of the organisation should identify the ERP need and appoint a vendor who can align the system to the organisation's strategic decisions (Sheik & Sulphey, 2020).

Insufficient end-user training

Training and re-skilling the employees for the newly implemented system should always be a priority for the organisation. Although this is the most expensive investment for an organisation, the organisation should always plan and be prepared for the costs as the ERP implementation comes with deadlines that need to be met. The case with the NYDA is that it was hard for the vendor to physically train the end-users and they resorted to pre-recorded training which did not give the users skills and the know-how of the system. The end-users' performance was affected for at least three months after the system was implemented.

The managers' open communication lines and their team-building skills are much more important when the ERP is introduced in the organisation (Badewi et al., 2018). The organisation should always involve the end-users in the ERP project to enable the vendors to be aware of users' requirements and to address users' concerns at the initial stage of the implementation (Ullah et al., 2020). The NYDA failed at involving the users of the system and that affected the transition. Users were reluctant to use the ERP as they had no skills to utilise the ERP system and were unaware of the impact the ERP project would have on their responsibilities. To prevent this, organisations should develop a communication plan, a demo, a video of training, and issue regular reports to keep users informed (Caserio & Trucco, 2018).

Lack of process integration

The adoption of the ERP is meant to ease the traditional processes and innovate the outputs while quickly delivering to the clients. The main processes that the ERP should be able to integrate include prototyping, functionalities of all products and services, and all subdivisions of the organisation. ERP features should enable all the technical aspects of the subdivisions of the organisation to work towards one objective. System integration is the major issue for organisations during ERP implementation and no application may do everything for any organisation to fulfil its needs (Kenge & Khan, 2020). With the NYDA, only the human resource sub-division was able to fully adopt the system with all its functions and incorporate them for the required outputs. All other divisions are still today not fully functional on the ERP due to poor integration of business processes and gaps in the product delivery process. Although the organisation may purchase different modules from different vendors and integrate them with

other business systems to have a full ERP system (Kurnia et al., 2019), the NYDA has to this day failed to integrate some products.

Resistance to change management

A lack of communication and knowledge of formalised business processes and ERP systems during the ERP implementation process may make the users more resistant to change. Top management failing to give their subordinates a chance to participate in BPR, a lack of use of the ERP system, and inferior quality of data entering the system may be the main causes of this resistance.

Most employees face difficulties with alterations or transformations, which mostly affects the status quo in the organisation. Ali et al. (2022) noticed that middle managers mostly resist the ERP implementation process, and the results may be that the ERP implementation faces internal resistance from the middle managers who are reluctant to give up the old ways of working or feel that the system will replace them. The NYDA employees felt that the change was forced upon them; there were too frequent changes regarding new technological solutions, their responsibilities were not clear in the system, and they were tired of coping with the constant change. Consequently, they were unwilling to accept any new system as they had "no choice".

Poor technology planning

A lack of adequate technical expertise and adequate technology infrastructure for supporting project requirements is a risk factor when implementing new software (Kohansal, 2019). Having a new project scope, new users, application complexity, and failure of technology to meet specifications may be a huge financial risk for the organisation. A lack of adequate technical expertise and technology infrastructure may be the biggest contribution to escalating time and cost overruns and may cause the rejection of the whole project by the organisation (Kohansal, 2019). In this study, most of the respondents had mentioned a lack of resources such as laptops and mobile connectivity, and yet the organisation is adopting the ERP system, which requires one to only use a laptop and no paperwork. The staff morale is already affected by being expected to deliver without having a laptop.

Security risks/data security

In cloud ERP, tenants of the same vendor share their data storage and other code processing which might raise significant security risks. Organisations need to prioritise data access protection as it is a vital component in cloud ERP security. An assurance of the safety of data against unauthorised access, use, and disclosure should always be the top priority. A comparison of the traditional IT systems to the ERP system shows that there are more threats and security risks in cloud ERP because of its dependence on distributed databases (Mahmood et al., 2019). The NYDA is still using traditional security mechanisms like passwords, firewalls,

and antivirus software, which no longer serve to assure the security of corporate information in a scenario where employees own and have total control of their devices. According to Mahmood et al. (2019) one of the main security challenges of ERP is the risk of loss of data or loss of the device which can lead to sensitive data landing in the wrong hands. Biometrics, face reading security access to the system, and any other contemporary security measures are not available at the NYDA, weakening the organisation's security.

6 KNOWLEDGE MANAGEMENT AND SUCCESSFUL IMPLEMENTATION OF ERP

The results from the mixed-methods study revealed that effective utilisation of knowledge is crucial for successful ERP implementation in a public sector organisation. The quantitative survey revealed a significant positive association between KM and ERP implementation, indicating a strong relationship between the two variables. Participants expressed the need for top management involvement and knowledge sharing to ensure the successful implementation of the ERP system. The importance of top management expertise in the implementation process was also emphasised by interviewees. Both methods support the idea that knowledge management activities, such as knowledge creation, sharing, and transfer among organisational members, contribute positively to ERP implementation and enhance the organisation's competitiveness.

The finding aligns with Salloum et al. (2018) suggestion that knowledge transfer occurs when knowledge owners, who are usually the top management team, deliver knowledge to knowledge seekers, who are typically subordinates. It also supports the findings of Leoni et al. (2022) who found that successful knowledge transfer leads to the construction of fully functional systems that are well understood by all employees instead of a particular group. Successful knowledge transfer requires the combination of appropriate people and techniques that contribute to the successful implementation of an ERP system.

The successful implementation of ERP is critical for an organisation's change management. This is supported by the study's findings, which reveal a positive correlation between ERP implementation and an understanding of changes by the employees in an organisation based on the surveys conducted. The results from the quantitative study demonstrate that positive change management can improve ERP implementation. The qualitative study also shows a positive association between change management and ERP implementation, as revealed by the respondents. Korenková et al. (2019) confirm that an organisation's ability to manage change is bound to offer an organisation a smooth and successful ERP implementation. Furthermore, Bellisario and Pavlov (2018) argue that innovation adoption is crucial for an organisation's change management in today's business environment.

The qualitative findings further support this, with respondents highlighting that better application of change management in the ERP implementation facilitates ease of adaptation to the system. These findings are consistent with Park (2018) who stressed the significance of making employees aware of the changes in business processes that the ERP would introduce and aligning their duties to the capabilities of the ERP. Mahmood et al. (2019) also underlined

the importance of synthesising the ERP with change management and business process changes following its implementation.

7 DISCUSSION AND RECOMMENDATIONS

The first anticipated theme pertains to the importance of top management support and knowledge sharing, which can greatly impact the successful implementation of an ERP system in the organisation. The second anticipated theme relates to end-user training aimed at promoting change management, which can also significantly impact the success of ERP implementation. The third anticipated theme highlights user involvement during the ERP implementation process to improve staff morale. The fourth anticipated theme underscores the significance of effective communication and knowledge transfer for successful ERP implementation. The fifth anticipated theme focuses on ERP organisation strategic alignment and data accuracy, which facilitate knowledge transfer and help ensure successful ERP implementation. Finally, the sixth anticipated theme involves post-implementation performance monitoring to improve organisation performance.

The interview responses confirm the importance of all these themes in facilitating successful ERP implementation. Therefore, management must ensure that all these themes are given proper attention and adhered to during the ERP implementation process. The theme of top management support and knowledge sharing is consistent with Jayeola et al. (2020) who posit that the involvement of top management in ERP implementation positively affects implementation success, particularly if they are willing to share knowledge to improve organisational performance. Given that ERP implementation leads to changes in the organisation, senior management involvement is necessary to resolve conflicts. Without a commitment from senior management, ERP implementation is at a high risk of failure. All participants emphasised the importance of knowledge sharing in the processes following the implementation of the ERP solution.

Wijaya et al. (2018) discussed the importance of end-user training in embracing change management. The study's second theme, end-user training, was found to be a necessary attribute of ERP implementation, enabling employees to adapt to the changes that come with the system. Gill et al. (2020) confirmed that end-user training has a positive impact on the adoption of ERP. Participants noted that training users was critical to facilitating their acceptance of the system and enabling them to transact with ease by the "go live" date. Nguyen et al. (2021) identified the challenge of ERP implementation caused by differences in the package's functionality and the vendor's requirements, leading to barriers and decreased organisational performance.

Regarding the third theme of user involvement during the ERP implementation to improve staff morale, the study participants had a positive response regarding this theme's association with successful ERP implementation. Stone and Zhang (2021) suggested that for an organisation to achieve successful ERP implementation, it is crucial to involve end-users. While top management is responsible for steering the implementation, end-users are the key drivers.

The involvement of end-users, who implement the program, ensures that business processes driven by the new ERP align with the organisation's needs. Additionally, Vincent and Premkumar (2021) found that involving users improves communication with the developers, leading to a better understanding of organisational needs and increased user satisfaction.

In relation to the anticipated theme of communication and knowledge transfer, the study participants agreed that regular communication is vital for successful ERP implementation. Effective communication channels ensure that suppliers are kept updated, and employees are informed of the project's status. Given that ERP is a system that spans across the company and involves cross-functional teams, effective communication, and coordination among different departments are critical (Samiei & Habibi, 2019). Effective communication has a positive impact on implementation success, significantly influences system acceptance, and helps to reduce resistance (Vaghefi et al., 2018).

According to the study participants, strategic alignment and data accuracy are crucial factors in successfully implementing ERP in an organisation, alongside the facilitation of knowledge transfer from top management to subordinates. Data quality and validation are essential for a successful ERP implementation, as the migration of data from legacy systems to newly implemented systems must be accurate. As noted by Eryadi and Hidayanto (2020) strategic direction and leadership commitment are critical to positively impact the effectiveness of any organisation's ERP implementation. The top management must work with the organisation's human resources to align competencies and skills, leadership vision, and willingness to change, and involve employees in planning and innovation to ensure the organisation's competitive edge. Chofreh et al. (2019) also underscored the importance of strategic alignment and leadership involvement in realising the organisational benefits of ERP IT systems. As ERP systems are highly integrated, data quality is expected to be a critical success factor for implementation.

Finally, the post-implementation performance monitoring of ERP helps decision-makers to assess the alignment of the system with the organisation's processes (Pohludka et al., 2018). Monitoring the system can improve process quality, reduce waste, and prevent employee frustration. Furthermore, it ensures that customer satisfaction is prioritised.

8 CONCLUSION

Technology is advancing at a very fast pace giving rise to the growing commitment of public sector organisations around the globe to service delivery excellence. To achieve these business aspirations and goals, organisation's processes become interrelated and more complex, causing ERP implementations to be tougher and more challenging than ever. This poses challenges to any public sector organisation that wants to pursue ERP implementation to select appropriate ERP tools and vendors to match the available infrastructure, employees' skills, and selection of appropriate implementation methodologies. The appropriate selection helps the organisation achieve operational efficiencies and effectiveness to stay competitive.

This study presents a thorough review and analysis of the literature that has built up a comprehensive knowledge and expertise base and a deeper understanding of what ERP is and

the features that organisations look for in ERP. It reports on the various reasons that led to a delayed ERP system implementation at NYDA and provides a comprehensive insight into users' initial experience.

This research unveils several intra-organisational challenges to the successful implementation of an ERP system. Inadequate end-user training, lack of integration of business processes, knowledge transfer, lack of top management support, resistance to change, change management, security threats, and poor technology initiatives have been cited as major challenges to successfully implementing the ERP system at the NYDA. With NYDA being a large organisation with multiple branches throughout South Africa, contextualisation of ERP and customisation of the processes from the users' perspective and system configuration were key aspects that had to be considered for the ERP implementation process.

The facts collected from both the interview and the questionnaires showed that the vendor hardly encouraged the users' participation at the outset of the project, particularly during the requirement elicitation stage and the end-users believe that they failed them from the onset. The vendor usually contacted the top management team, who are not the implementors of the products on the ground and do not get involved in the processes of the product delivery rather than end-users. Such a situation caused a gap between what the users wanted and what eventually was delivered for the system they most interact with.

This study helped to understand different challenges relating to the implementation of ERP solutions at the NYDA. It is clear from the facts collected that the vendor started development work with minimal understanding of the business processes of the organisation and was not concerned about the involvement of end-users during requirement elicitation. This has led to an extensive gap between "what ERP system delivered and what users want, and all are at a stand-still". With the delivery of the first full release in December 2020, the users could not perform a single product from the beginning to the end due to huge gaps between the processes. The ERP system was not in line with their current business process, and the system was not used by the organisation for almost the full year of that initial delivery leading to its disappointment. The research findings show that top management hardly realise the importance of user involvement and their training in the system usage and did not encourage their participation at the outset of the project. Due to a lack of management support, the users were not enthusiastic about being part of the implementation process and that resistance to change led to low staff morale, affecting the organisation's performance. Consequently, the users pretended that the system is not user-friendly, so they did not use it.

The vendor was unable to understand and align the ERP to the processes of the NYDA for them to integrate and perform well. It seemed to be complex for the vendor to deliver business processes of the NYDA as it was their first experience developing and implementing such a large, complex, and public sector ERP system. Lack of vendor experience affected the quality of the final product, consequently leading to project cost overrun and being behind schedule. The ERP system under study was outsourced, so was developed and implemented by a multi-national vendor. The findings showed a lack of user involvement, lack of top management support, lack of vendors' experience and support, and lack of change management as

impediments to ERP's successful implementation.

References

Aberdeen, T. (2013). Yin, R. K. (2009). Case study research: Design and methods (4th Ed.). Thousand Oaks, CA: Sage. *The Canadian Journal of Action Research*, *14*(1), 69–71. https://doi.org/10.33524/cjar.v14i1.73

Abusweilem, M. A., & Abualous, S. (2019). The impact of knowledge management process and business intelligence on organizational performance. *Management Science Letters*, 2143–2156. https://doi.org/10.5267/j.msl.2019.6.020

Ain, N., Vaia, G., DeLone, W. H., & Waheed, M. (2019). Two decades of research on business intelligence system adoption, utilization and success – a systematic literature review. *Decision Support Systems*, *125*, 113113. https://doi.org/10.1016/j.dss.2019.113113

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-t

Albarghouthi, M., Qi, B., Wang, C., & Abbad, M. (2020). ERP adoption and acceptance in Saudi Arabia higher education: A conceptual model development. *International Journal of Emerging Technologies in Learning (iJET)*, *15*(15), 110. https://doi.org/10.3991/ijet.v15i15.12039

Ali, M., Edghiem, F., & Alkhalifah, E. S. (2022). Cultural challenges of ERP implementation in Middle-Eastern oil & gas sector: An action research approach. *Systemic Practice and Action Research*, *36*(1), 111–140. https://doi.org/10.1007/s11213-022-09600-4

Alieva, J., & Haartman, R. V. (2021). Digital collaboration within the supply chain: Unlocking the hidden lean potential. *International Journal of Advanced Operations Management*, *13*(1). https://doi.org/10.1504/ijaom.2021.113663

Al-Mashari, M., Zairi, M., & Okazawa, K. (2006). Enterprise resource planning (ERP) implementation: A useful road map. *International Journal of Management and Enterprise Development*, *3*(1/2), 169. https://doi.org/10.1504/ijmed.2006.008248

Andreeva, T., & Kianto, A. (2012). Does knowledge management really matter? Linking knowledge management practices, competitiveness and economic performance (G. Schiuma, Ed.). *Journal of Knowledge Management*, *16*(4), 617–636. https://doi.org/10.1108/13673271211246185

Azima, Y. F., Azizah, A. H., & Witjaksono, R. W. (2019). Analisis penerimaan pengguna terhadap sistem ERP pada fungsi after sales menggunakan model technology acceptance model 2 (TAM2). *Jurnal Rekayasa Sistem & Industri (JRSI)*, *6*(02), 65. https://doi.org/10.25124/jrsi.v6i02.328

Badewi, A., Shehab, E., Zeng, J., & Mohamad, M. (2018). ERP benefits capability framework: Orchestration theory perspective. *Business Process Management Journal*, *24*(1), 266–294. https://doi.org/10.1108/bpmj-11-2015-0162

Bandura, A. (1989). Human agency in social cognitive theory. *American Psychologist*, *44*(9), 1175–1184. https://doi.org/10.1037/0003-066x.44.9.1175

Bellisario, A., & Pavlov, A. (2018). Performance management practices in lean manufacturing organizations: A systematic review of research evidence. *Production Planning & Control*, *29*(5), 367–385. https://doi.org/10.1080/09537287.2018.1432909

Beydoun, G., Abedin, B., Merigó, J. M., & Vera, M. (2019). Twenty years of information systems frontiers. *Information Systems Frontiers*, *21*(2), 485–494. https://doi.org/10.1007/s10796-019-09925-x

Caserio, C., & Trucco, S. (2018). Business intelligence systems. In *Enterprise resource planning and business intelligence systems for information quality* (pp. 43–73). Springer International Publishing. https://doi.org/10.1007/978-3-319-77679-8_3

Chaushi, B. A., Chaushi, A., Dika, Z., & Ismaili, F. (2018). Investigation of higher education ERP implementation factors. *Proceedings of the 19th International Conference on Computer Systems and Technologies*. https://doi.org/10.1145/3274005.3274008

Chofreh, A. G., Goni, F. A., Malik, M. N., Khan, H. H., & Klemes, J. J. (2019). Evaluation of the sustainable enterprise resource planning implementation steps. *Chemical Engineering Transactions*, *72*, 445–450. https://doi.org/10.3303/CET1972075

Compeau, D., Higgins, C. A., & Huff, S. (1999). Social cognitive theory and individual reactions to computing technology: A longitudinal study. *MIS Quarterly*, *23*(2), 145. https://doi.org/10.2307/249749

Davis, F. D. (1986). *A technology acceptance model for empirically testing new end-user information systems: Theory and results* [Doctoral dissertation, Massachusetts Institute of Technology]. http://hdl.handle.net/1721.1/15192

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace. *Journal of Applied Social Psychology*, *22*(14), 1111–1132. https://doi.org/10.1111/j.1559-1816.1992.tb00945.x

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Springer US. https://doi.org/10.1007/978-1-4899-2271-7

de Oliveira, A., & de Almeida, J. R. (2019). Business intelligence application for multidimensional analysis of risks in complex projects. *IT Professional*, *21*(6), 33–39. https://doi.org/10.1109/mitp.2018.2876931

Eryadi, R. A., & Hidayanto, A. N. (2020). Critical success factors for business intelligence implementation in an enterprise resource planning system environment using DEMATEL: A case study at a cement manufacture company in Indonesia. *Journal of Information Technology Management*, *12*(1). https://doi.org/10.22059/jitm.2020.296055.2460

Gavidia, J. V., Junglas, I. A., & Chou, C.-H. (2021). An integrated model of ERP success: The critical role of task-context alignment. *Enterprise Information Systems*, *17*(1). https://doi.org/10.1080/17517575.2021.1931460

Gill, A. A., Amin, S., & Saleem, A. (2020). Investigation of critical factors for successful ERP implementation: An exploratory study. *Journal of Business and Social Review in Emerging Economies*, *6*(2), 565–575. https://doi.org/10.26710/jbsee.v6i2.1183

Gupta, S., Qian, X., Bhushan, B., & Luo, Z. (2019). Role of cloud ERP and big data on firm performance: A dynamic capability view theory perspective. *Management Decision*, *57*(8), 1857–1882. https://doi.org/10.1108/md-06-2018-0633

Holland, C., & Light, B. (1999). Global enterprise resource planning implementation. *Proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences. 1999. HICSS-32*. https://doi.org/10.1109/hicss.1999.772762

Huang, T., & Yokota, A. (2018). Inventing a business-ERP alignment assessment model through three Japanese companies. *Business Process Management Journal*, *25*(4), 738–756. https://doi.org/10.1108/bpmj-03-2017-0068

Jayeola, O., Sidek, S., Rahman, A. A., Mahomed, A. S. B., & Jimin, H. (2020). Contextual factors and strategic consequences of cloud enterprise resource planning (ERP) adoption in Malaysian manufacturing SMEs: A conceptual framework. *International Journal of Economics and Business Administration*, *VIII*(3), 176–201. https://doi.org/10.35808/ijeba/495

Jenab, K., Staub, S., Moslehpour, S., & Wu, C. (2019). Company performance improvement by quality based intelligent-ERP. *Decision Science Letters*, 151–162. https://doi.org/10.5267/j.dsl.2018.7.003

Kang, C., Ma, F., Li, S., Kroll, J. F., & Guo, T. (2020). Domain-general inhibition ability predicts the intensity of inhibition on non-target language in bilingual word production: An ERP study. *Bilingualism: Language and Cognition*, *23*(5), 1056–1069. https://doi.org/10.1017/s1366728920000085

Kenge, R., & Khan, Z. (2020). A research study on the ERP system implementation and current trends in ERP. *Shanlax International Journal of Management*, *8*(2), 34–39. https://doi.org/10.34293/management.v8i2.3395

Kianto, A., Ritala, P., Vanhala, M., & Hussinki, H. (2020). Reflections on the criteria for the sound measurement of intellectual capital: A knowledge-based perspective. *Critical Perspectives on Accounting*, *70*, 102046. https://doi.org/10.1016/j.cpa.2018.05.002

Kiran, T. S., & Reddy, A. V. (2019). Critical success factors of ERP implementation in SMEs. *Journal of Project Management*, (4), 267–280. https://doi.org/10.5267/j.jpm.2019.6.001

Kohansal, M. A. (2019). Lessons from failure ERP implementation. *Norsk konferanse for organisasjoners bruk av informasjonsteknologi (NOKOBIT 2019)*. https://www.researchgate.net/publication/337608576_LESSONS_FROM_FAILURE_ERP_IMPLEMENTATIONS

Korenková, V., Závadský, J., & Lis, M. (2019). Linking a performance management system and competencies: Qualitative research. *Engineering Management in Production and Services*, *11*(1), 51–67. https://doi.org/10.2478/emj-2019-0004

Kujala, V., & Halonen, R. (2019, April). Business growth using open source e-commerce and ERP in small business. In *Intelligent systems design and applications* (pp. 147–158). Springer International Publishing. https://doi.org/10.1007/978-3-030-16657-1_14

Kurnia, S., Linden, T., & Huang, G. ((2019). A hermeneutic analysis of critical success factors for enterprise systems implementation by SMEs. *Enterprise Information Systems*, *13*(9), 1195–1216. https://doi.org/10.1080/17517575.2019.1650960

Leoni, L., Ardolino, M., El Baz, J., Gueli, G., & Bacchetti, A. (2022). The mediating role of knowledge management processes in the effective use of artificial intelligence in manufacturing firms. *International Journal of Operations & Production Management*, *42*(13), 411–437. https://doi.org/10.1108/ijopm-05-2022-0282

Mahmood, F., Khan, A. Z., & Bokhari, R. H. (2019). ERP issues and challenges: A research synthesis. *Kybernetes*, *49*(3), 629–659. https://doi.org/10.1108/k-12-2018-0699

Markus, M. L., & Tanis, C. (2000). The enterprise system experience – from adoption to success. In R. W. Zmud (Ed.), *Framing the domains of IT management: Projecting the future through the past* (pp. 173–207). Pinnaflex Educational Resources Inc., Cincinnati. http://pro.unibz.it/staff/ascime/documents/ERP%20paper.pdf

Markus, M. L., Tanis, C., & van Fenema, P. C. (2000). Enterprise resource planning: Multisite ERP implementations. *Communications of the ACM*, *43*(4), 42–46. https://doi.org/10.1145/332051.332068

Menon, S. A., Muchnick, M., Butler, C., & Pizur, T. (2019). Critical challenges in enterprise resource planning (ERP) implementation. *International Journal of Business and Management*, *14*(7), 54. https://doi.org/10.5539/ijbm.v14n7p54

Mugenda, O. M., & Mugenda, A. G. (1999). *Research methods: Quantitative and qualitative approaches*. African Centre for Technology Studies.

Nguyen, T. H., Nguyen, Q. T., & Vu, L. D. H. (2021). The effects of accounting benefit, ERP system quality and management commitment on accountants' satisfaction. *Accounting*, (7), 127–136. https://doi.org/10.5267/j.ac.2020.10.005

Oliveira, M., Curado, C., Balle, A. R., & Kianto, A. (2020). Knowledge sharing, intellectual capital and organizational results in SMEs: Are they related? *Journal of Intellectual Capital*, *21*(6), 893–911. https://doi.org/10.1108/jic-04-2019-0077

Paksoy, T., Kochan, C. G., & Ali, S. S. (2021, December). *Logistics 4.0: Digital transformation of supply chain management*. Routledge, Taylor & Francis Group. https://doi.org/10.1201/9780429327636

Park, K. (2018). The relationship between BPR strategy and change management for the sustainable implementation of ERP: An information orientation perspective. *Sustainability*, *10*(9), 3080. https://doi.org/10.3390/su10093080

Perez-Estebanez, R., Urquía-Grande, E., & Rautiainen, A. (2017). Technological and economic factors determining ICT level: Evidence from rural micro-businesses in Democratic Republic of Congo. *Journal of International Development*, *30*(1), 118–133. https://doi.org/10.1002/jid.3281

Pohludka, M., Stverkova, H., & Slusarczyk, B. (2018). Implementation and unification of the ERP system in a global company as a strategic decision for sustainable entrepreneurship. *Sustainability*, *10*(8), 2916. https://doi.org/10.3390/su10082916

Rani, S., Mishra, R. K., Usman, M., Kataria, A., Kumar, P., Bhambri, P., & Mishra, A. K. (2021). Amalgamation of advanced technologies for sustainable development of smart city environment: A review. *IEEE Access*, *9*, 150060–150087. https://doi.org/10.1109/access.2021.3125527

Ranjan, S., Jha, V. K., & Pal, P. (2016). Literature review on ERP implementation challenges. *International Journal of Business Information Systems*, *21*(3), 388. https://doi.org/10.1504/ijbis.2016.074766

Ruivo, P., Johansson, B., Sarker, S., & Oliveira, T. (2020). The relationship between ERP capabilities, use, and value. *Computers in Industry*, *117*, 103209. https://doi.org/10.1016/j.compind.2020.103209

Salloum, S. A., Mhamdi, C., Al Kurdi, B., & Shaalan, K. (2018). Factors affecting the adoption and meaningful use of social media: A structural equation modeling approach. *International Journal of Information Technology and Language Studies*, *2*(3), 96–109. https://journals.sfu.ca/ijitls/index.php/ijitls/article/view/49

Samiei, E., & Habibi, J. (2019). The mutual relation between enterprise resource planning and knowledge management: A review. *Global Journal of Flexible Systems Management*, *21*(1), 53–66. https://doi.org/10.1007/s40171-019-00229-2

Saunders, M. N., Lewis, P., & Thornhill, A. (2023). *Research methods for business students* (9th ed.). Pearson Harlow, England. https://www.pearson.com/en-gb/subject-catalog/p/research-methods-for-business-students/P200000010080/9781292402727

Secundo, G., Lombardi, R., Dumay, J., & Guthrie A.M., J. (2023). Reflecting on intellectual capital measurement and management in European universities. *Meditari Accountancy Research*, *31*(6), 1827–1845. https://doi.org/10.1108/medar-03-2022-1632

Sheik, P. A., & Sulphey, M. (2020). Enterprise resource planning (ERP) as a potential tool for organizational effectiveness. *Webology*, *17*(2), 317–327. https://doi.org/10.14704/web/v17i2/web17034

Stone, A. R., & Zhang, X. (2021). Understanding success factors for ERP implementation: An integration of literature and experience. *Issues In Information Systems*, *22*(2), 146–156. https://doi.org/10.48009/2_iis_2021_150-161

Sumner, M. (2000). Risk factors in enterprise-wide/ERP projects. *Journal of Information Technology*, *15*(4), 317–327. https://doi.org/10.1177/026839620001500407

Taylor, S., & Todd, P. (1995). Decomposition and crossover effects in the theory of planned behavior: A study of consumer adoption intentions. *International Journal of Research in Marketing*, *12*(2), 137–155. https://doi.org/10.1016/0167-8116(94)00019-k

Ullah, A., Bin Baharun, R., Yasir, M., & Nor, K. M. (2020). Enterprise resource planning systems and user performance in higher education institutions of Pakistan. *Journal of Applied Economics and Business Studies*, *4*(2), 119–140. https://doi.org/10.34260/jaebs.426

Vaghefi, I., Lapointe, L., & Shahbaznezhad, H. (2018). A multilevel process view of organizational knowledge transfer: Enablers versus barriers. *Journal of Management Analytics*, *5*(1), 1–17. https://doi.org/10.1080/23270012.2018.1424572

Vincent, A. G. M., & Premkumar, M. D. (2021). A study on impact of effective implementation of enterprise resource planning on organization in selected construction chemical companies in Chennai. *Annals of the Romanian Society for Cell Biology*, *25*(4), 3537–3553. https://annalsofrscb.ro/index.php/journal/article/view/2905

Wang, W., Luo, M., & Chang, Y. (2021). Exploring the relationship between conflict management and transformational leadership behaviors for the success of ERP customization. *Information Systems Management*, *39*(2), 177–200. https://doi.org/10.1080/10580530.2021.1913680

Weeger, A., & Gewald, H. (2013). Examining social and cognitive aspects determining physician's adoption of electronic medical records. *21st European Conference on Information Systems, ECIS 2013*, 66. https://aisel.aisnet.org/ecis2013_cr/66/

Wijaya, R. A., Widyaningrum, P., Prasetyo, B., & Satria, R. (2018). Analyzing of implementation enterprise budgeting system using SAP BPC: Case study on a financial government institution. *2018 International Conference on Advanced Computer Science and Information Systems (ICACSIS)*. https://doi.org/10.1109/icacsis.2018.8618253

Zuma, N. I., & Sibindi, N. (2023). Knowledge management as a driver of successful enterprise resources planning implementation: A conceptual framework. *Change Management: An International Journal*, *23*(1), 37–62. https://doi.org/10.18848/2327-798x/cgp/v23i01/37-62

A QUANTITATIVE INSTRUMENT

Table 1: Benefits of cloud computing

Item	Source	Example of question
Alignment	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- What is the association between ERP and your work?
Product Quality and Support	Al-Mashari et al. (2006) Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- Rank the usefulness of the support given.
Top management support	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- Indicate the management support given.
End-user training	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- Indicate the type of end-user training that you received. - Training was adequate. - The training was practical with all relevant materials.
Change management	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- Organisational readiness to change was regularly assessed. - How prepared were you to use ERP? - ERP was easily adaptable to business changes. - There was clear communication during the implementation stages.
Process integration	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- ERP brought easy processes to all deliverables. - How long did it take you to migrate? - Migration of data from the traditional system to ERP was easy.
Technology Planning	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- The technological changeover was smooth. - The technology used matched my duties. - Was the technology infrastructure adequate? - Level of technological expertise.
Risk and security matters	Ranjan et al. (2016) Sumner (2000) Menon et al. (2019)	- Risk of failing to perform your duties when using ERP.

https://doi.org/10.18489/sacj.v35i2.17410

B INTERVIEW GUIDE

ERP package knowledge

- Do you think the ERP implementation process was handled in a correct manner?
- Was the introduction of staff members handled completely?
- Which area of the ERP system do you find most challenging?
- How do you plan to overcome this challenge? How was your experience?
- Was there prior communication regarding the need for ERP in the organisation?
- Do you think the ERP is fit for the organisation?

Training for ERP

- Do you think it is necessary to have training for the system before its implementation?
- Was there any training given for the system?
- Was the training enough to understand the system?
- Do you have any platform to direct any queries or difficulties experienced when using the system?
- What is the significant difference between the ERP and the traditional system?
- What were the main challenges you experienced during the ERP implementation stage? Were they resolved?
- Do you think your morale ever changed during the implementation phase of the ERP?
- Was it a negative or a positive change?

Outputs and expectations

- Do you think the system meets your expectations? Does it do what it was meant for?
- Have you had any projects completed using the ERP system? How was your experience?
- How is the efficiency of the system compared to the traditional system the organisation had?
- Has the average time taken to complete the project changed while using the ERP system as compared to the traditional system?
- Are there any significant changes you have noticed since using the ERP system on the delivery, of services in the organisation?

https://doi.org/10.18489/sacj.v35i2.17410

SACJ 35(2) December 2023
Viewpoint

Natural Language-Driven Dialogue Systems for Support in Physical Medicine and Rehabilitation

Vladislav Kaverinsky[a], Kyrylo Malakhov[b]

[a] Frantsevic Institute for Problems in Material Science of the National Academy of Sciences of Ukraine, Kyiv, Ukraine
[b] Microprocessor technology lab, Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

ABSTRACT
This paper presents a natural language-driven dialogue system designed to support healthcare professionals and students in the field of physical medicine and rehabilitation. The system seamlessly integrates concepts from intelligent information systems, data mining, ontologies, and human-computer interaction, employing at its core a rule-based dialogue mechanism. The system harnesses the power of ontology-based graph knowledge, underscoring its domain-specific efficacy. This article delves into the automated knowledge base formation, utilising Python scripts to translate EBSCO's dataset of articles on physical medicine and rehabilitation into an OWL ontology. This methodology ensures adaptability to the ever-evolving landscape of medical insights. The system's approach to natural language processing encompasses text preprocessing, semantic category discernment, and SPARQL query creation, providing 26 predefined categories. As an innovation in performance optimisation, the system integrates a strategy to cache precomputed responses using a PostgreSQL database, which aids in resource conservation and reduction in query execution latency. The system's user engagement avenues are further detailed, showcasing a Telegram bot and an API, enhancing accessibility and user experience. In essence, this article illuminates an advanced, efficient dialogue system for physical medicine and rehabilitation, synthesising multiple computational paradigms, and standing as a beacon for healthcare practitioners and students alike.

Keywords Ontology engineering, Ontology learning, Knowledge management, Knowledge base, SPARQL, Natural Language-Driven Dialogue System, Human-Computer interaction, MedRehabBot

Categories • **Artificial intelligence** ∼ **Natural language processing, Discourse, dialogue and pragmatics**

Email
Vladislav Kaverinsky – insamhlaithe@gmail.com,
Kyrylo Malakhov – malakhovks@nas.gov.ua (CORRESPONDING)

1 INTRODUCTION

Natural language-driven dialogue systems, colloquially known as chatbots, have evolved through a rich historical lineage encompassing diverse methodologies. Their appeal spans various sectors due to their ability to offer a user-friendly interface, particularly beneficial for users unfamiliar with intricate database queries or programming. Such systems allow users to pose questions or describe problems effortlessly, receiving detailed responses that not only

Kaverinsky, V., and Malakhov, K. (2023). Natural Language-Driven Dialogue Systems for Support in Physical Medicine and Rehabilitation [Viewpoint]. *South African Computer Journal* 35(2), 119–126. https://doi.org/10.18489/sacj.v35i2.17444

SACJ is a publication of *SAICSIT*. ISSN 1015-7999 (print) ISSN 2313-7835 (online)

encompass textual information but can also include tables, illustrations, and multimedia content. Given their capabilities and versatility, it is evident why there is a burgeoning interest in these dialogue systems, driving continuous advancements in the field.

2 AN OVERVIEW OF DEVELOPMENT APPROACHES AND TRENDS IN NATURAL LANGUAGE-DRIVEN DIALOGUE SYSTEMS

In the realm of contemporary dialogue systems, there has been a notable emergence of those harnessing computer ontologies. For instance, an analysis of a natural language-driven dialogue system tailored for English (Quamar, Lei et al., 2020; Quamar, Özcan et al., 2020) suggests that English sentences generally adhere to a consistent structural pattern, which can be represented using predefined templates. These templates consist of a static segment indicating the primary semantic intention and variable elements identifying the corresponding conceptual placeholders. These placeholders are carefully designed to match the anticipated intentions of the expected conceptual entities.

Another noteworthy system rooted in natural language transformation using SPARQL techniques, is FREyA (Damljanovic et al., 2012). Accessible publicly on GitHub (Kumar, 2022), FREyA offers an interactive interface for querying ontology-based databases. It combines parsing with ontology searches to interpret user queries, and when required, prompts users for added clarity. The system also improves its performance based on user interactions, enhancing query accuracy. Currently, FREyA is designed specifically for English, with the GitHub repository (Kumar, 2022) illustrating how it translates natural language queries into SPARQL. Crucially, FREyA's design is flexible enough to fit different ontology architectures.

In today's natural language-driven dialogue system landscape, large language models (LLM), like ChatGPT (OpenAI, 2023), are prominent. Despite their unparalleled capabilities, their extensive computational requirements and the necessity for specialised training render them not innately optimised for specific domains. As such, rule-based models maintain their significance and can be synergistically paired with LLMs for enhanced analytical power (Palagin et al., 2023).

In previous research (Litvin et al., 2023), we developed an ontology-driven dialogue system for the medical domain. The ontology used differed in structure and methodology, focusing on a detailed semantic evaluation of text, especially named entities and their relations. For texts with a consistent format, operating at an elevated abstraction level is viable. That research employed Neo4J as the preferred graph database system, using the Cypher query language. Yet, the more traditional Jena Fuseki and SPARQL queries are worthy of consideration for ontology-centric knowledge systems.

In summary, this paper offers an academic insight into recent natural language-driven dialogue system innovations, underscoring their adaptability across varied disciplines. We highlight the enduring relevance of rule-based models amidst the rise of LLMs, advocating for a balanced understanding of their roles in specific contexts. The article also emphasises the

https://doi.org/10.18489/sacj.v35i2.17444

evolution of ontology-based systems to address varying textual structures, promoting deeper comprehension and user-friendly interactions. We advocate for further research into knowledge systems leveraging different technologies, ensuring methodologies are tailored to the unique needs of individual domains.

3 AUTOMATIC KNOWLEDGE BASE FORMATION TECHNIQUE

The natural language-driven dialogue system detailed herein harnesses an ontology-based graph knowledge base (Palagin et al., 2014; Palagin et al., 2018) and notably refrains from integrating neural network models. Opting instead for intent and entity detection in user input, it pinpoints these based on specific marker word lists. This methodology has demonstrated robust efficacy within the realm of physical medicine and rehabilitation. Not only does it ensure rapid response times, but it is also more resource-efficient than LLMs.

The foundational layer of this system, its knowledge base, is auto-generated using a dataset of *EBSCO articles* (Malakhov et al., 2023) encompassing physical medicine and rehabilitation domain knowledge. This dataset spans 1 013 PDF files, cumulatively accounting for 192 MB. All articles are penned in English. A distinct hallmark of this automated knowledge base generation lies in the standardised and predefined structure of these files, which acts as a guiding blueprint for the software. Custom Python scripts have been crafted to streamline the knowledge base's inception, shaping it as an OWL ontology in RDF/XML notation. This transformation unfolds in a bifurcated process. Initially, textual data is mined from the PDFs, whereupon its content – encompassing chapters and topics – is automatically structured into defined JSON configurations. As a result, a suite of JSON files emerges, each mirroring its source PDF and delineating its organised content.

Subsequent to this, the second phase instigates the creation of an OWL ontology, drawing from the amassed JSON configurations. The inherent hierarchy of the JSON dictionary keys provides the architecture for the OWL class system. Meanwhile, the paired context values evolve into designated individuals nested within their pertinent classes. Each article's file name undergoes metamorphosis into a named individual under the *Articles* class. An intrinsic OWL property, termed *Relate to article*, forges linkages between these contexts and their affiliated articles. Identified named entities within these contexts further evolve into designated individuals, housed within the *Word* class. These are then interconnected to their relevant contexts via the *Relate to context* OWL property. This intricate design permits the extraction of specific contexts from the ontology via SPARQL queries. Given the voluminous nature of the resultant knowledge base, it has been fragmented into ten segments, facilitating simultaneous querying.

https://doi.org/10.18489/sacj.v35i2.17444

4 THE PROPOSED DIALOGUE SYSTEM OPERATING DESCRIPTION

A rule-based natural language-driven dialogue system has been devised to cater to medical rehabilitation support. Primarily designed for medical professionals and students in the physical medicine and rehabilitation domain, it stands as an invaluable informational asset.

The system, equipped with a natural language user interface, also offers an API to facilitate interactions with other applications through specifically structured POST requests. At present, users can engage with the system through a Telegram bot.

The backbone algorithms that govern the system's functionality reside within a Python server application. Apache Jena Fuseki (triplestore and SPARQL server) is the chosen tool for interfacing with the ontological knowledge base. Key modules in the Python application include:

`preprocess_input.py` – This performs an initial analysis of the user's message to discern the inherent semantic categories (intents).

`form_queries.py` – Tasked with crafting SPARQL query packages.

`process_queries.py` – Overseeing the execution of queries on the Apache Jena Fuseki triplestore and interpreting their outcomes.

`processor.py` – It harmonises the operations of the aforementioned modules, ensuring a seamless transition from input reception to response formulation.

Additionally, the system's architecture integrates:

`webhook.py` – Serving to establish a connection with the Telegram messaging platform.

`api.py` – Detailing the API functions for the system.

Upon receiving a user's text input – either via the user interface or the API – the initial step involves purging it of any alien characters. The NLTK library then assists in breaking the text into individual word tokens which are subsequently lemmatised. Stop words, along with words absent in the physical medicine and rehabilitation domain knowledge base, are eliminated. What remains is a condensed list of semantically potent words.

The subsequent stage focuses on identifying and cataloguing specific semantic categories present in the user's message. Each category relates to a designated SPARQL query template in the system. As of now, 26 such categories exist, although the system's design facilitates future expansions.

The system's ability to pinpoint a semantic category is hinged on the detection of certain marker words from a pre-defined list. Each category-to-marker-word correlation is laid out in the `marker_words.json` file. The system's mechanism evaluates the input word list against this repository to assign a category.

https://doi.org/10.18489/sacj.v35i2.17444

The `form_queries.py` module emerges as the cornerstone in moulding SPARQL queries. Every distinct semantic category corresponds to a tailored SPARQL query template, all of which are stored in the `query_templates.json` file.

The Apache Jena Fuseki triplestore, in concert with the `processy_queries.py` module, oversees the execution of SPARQL queries. Recognising the intensive nature of this operation, the system distributes the queries across multiple threads to enhance efficiency. The outcomes of these queries, represented as JSON tables, may be sourced from one or several ontology sections.

However, the raw response obtained from Apache Jena Fuseki is not ideally structured for direct user presentation. The module, therefore, reshapes this data into a more digestible, tree-like structure following instructions detailed in the query templates outputs section.

To counteract the time-intensive nature of SPARQL queries, the system incorporates a cache mechanism, utilising a PostgreSQL-managed relational database to store precomputed responses.

For a more direct user interaction, a Telegram bot, **MedRehabBot** – @MedicalRehabBot (Kaverinsky & Malakhov, 2023a), has been introduced. The `webhook.py` module makes this engagement possible, leaning on the telebot package to communicate with Telegram's API.

Complementing the dialogue interface, the system presents a programmatic interface, articulated in the `api.py` module. Though it functions independently of `webhook.py`, it utilises the system's core modules. POST processing of API requests is orchestrated by the Flask framework. Upon server deployment, the standard server transitions to Gunicorn.

5 CONCLUSIONS

This paper introduces a comprehensive framework for the natural language-driven dialogue system, meticulously designed to offer vital support in the physical medicine and rehabilitation domain. Our holistic approach is an amalgamation of diverse disciplines such as intelligent information systems, data mining, ontologies, and human-computer interaction, culminating in a groundbreaking tool tailored for both healthcare professionals and students in the physical medicine and rehabilitation field (Malakhov, 2023a; Palagin, Malakhov, Velychko, Semykopna & Shchurov, 2022).

Central to our system is the knowledge base formation process. Harnessing the power of custom Python scripts and a vast collection of articles centred on physical medicine and rehabilitation from EBSCO, we have championed an auto-generation technique for creating an OWL ontology in RDF/XML format. Beyond streamlining the adaptability of the system to ever-evolving medical insights, this method underpins a robust data-driven decision support infrastructure.

A pivotal component of our system is its prowess in natural language processing. Incorporating stages like text preprocessing, discerning semantic categories, and crafting SPARQL queries, our design boasts 26 predefined categories, with built-in flexibility for future expansion.

https://doi.org/10.18489/sacj.v35i2.17444

By harnessing the Apache Jena Fuseki triplestore and SPARQL server for swift and efficient SPARQL query execution – enhanced further with multi-threading – we guarantee prompt retrieval of pivotal information. Furthermore, our system adeptly refines query outputs into a cohesive, hierarchical format, maximising both user interaction experience and API response efficacy.

6 ACKNOWLEDGEMENTS

The research team at the Glushkov Institute of Cybernetics extends heartfelt gratitude to Katherine Malan, the esteemed editor-in-chief of the South African Computer Journal. We deeply appreciate her steadfast commitment and dedication to advancing Ukrainian scientific endeavors during challenging wartime conditions, ensuring our contributions reach a global scholarly audience.

7 FUNDING

This study would not have been possible without the financial support of the National Research Foundation of Ukraine (Open Funder Registry: 10.13039/100018227). Our work was funded by Grant contract (application ID: 2021.01/0136):

> *Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modeling* (Malakhov, 2022, 2023b; Palagin, Malakhov, Velychko & Semykopna, 2022; Stetsyuk et al., 2023).

8 DATA AVAILABILITY

The data that support the findings of this study are derived from multiple sources, ensuring a comprehensive and detailed foundation for the Natural Language-Driven Dialogue System.

EBSCO Articles Dataset:

- *Domain Knowledge*: This dataset specifically pertains to rehabilitation medicine. With a collection of articles dedicated to this medical specialisation, it provides a rich source of knowledge that creates the system's core.
- *Data Format*: Every article from this dataset has been meticulously processed and represented in a structured JSON format. This ensures uniformity and ease of integration with the system's architecture.
- *Publicly available*: via Zenodo (Malakhov et al., 2023)

MedRehabBot:

- *Description*: MedRehabBot serves as an interactive reference system tailor-made for Physical Rehabilitation & Telerehabilitation. It caters to a broad audience, including Therapists, Students, and Patients, aiming to provide support and information.
- *Functionality*: As a pivotal component of our study, MedRehabBot is more than just a chatbot. It leverages the knowledge from the aforementioned EBSCO articles dataset and integrates with the dialogue system, ensuring real-time, relevant responses to users' queries.
- *Publicly available*: via GitHub (Kaverinsky & Malakhov, 2023b)

9 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.

References

Damljanovic, D., Agatonovic, M., & Cunningham, H. (2012). FREyA: An interactive way of querying linked data using natural language. In R. García-Castro, D. Fensel & G. Antoniou (Eds.), *The semantic web: ESWC 2011 workshops* (pp. 125–138). Springer. https://doi.org/10.1007/978-3-642-25953-1_11

Kaverinsky, V., & Malakhov, K. (2023a, September). MedRehabBot. https://t.me/MedicalRehabBot

Kaverinsky, V., & Malakhov, K. (2023b, September). MedRehabBot. https://github.com/knowledge-ukraine/MedRehabBot

Kumar, V. (2022, December). FREyA. https://github.com/nmvijay/freya

Litvin, A., Palagin, O., Kaverinsky, V., & Malakhov, K. (2023). Ontology-driven development of dialogue systems. *SACJ*, *35*(1), 37–62. https://doi.org/10.18489/sacj.v35i1.1233

Malakhov, K. (2022). Letter to the editor – update from Ukraine: Rehabilitation and research. *International Journal of Telerehabilitation*, *14*(2), 1–2. https://doi.org/10.5195/ijt.2022.6535

Malakhov, K. (2023a). Insight into the digital health system of Ukraine (eHealth): Trends, definitions, standards, and legislative revisions. *International Journal of Telerehabilitation*, *15*(2). https://doi.org/10.5195/ijt.2023.6599

Malakhov, K. (2023b). Letter to the editor – update from Ukraine: Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modeling. *International Journal of Telerehabilitation*, *15*(1). https://doi.org/10.5195/ijt.2023.6562

Malakhov, K., Vakulenko, D., & Kaverinsky, V. (2023, September). EBSCO articles dataset (domain knowledge: Rehabilitation medicine) + JSON of every article. https://doi.org/10.5281/ZENODO.8308214

OpenAI. (2023, March). *GPT-4 technical report* (tech. rep.) (arXiv:2303.08774 [cs]). OpenAI. arXiv. https://doi.org/10.48550/arXiv.2303.08774

Palagin, O., Malakhov, K., Velychko, V., Semykopna, T., & Shchurov, O. (2022). Hospital information smart-system for hybrid e-rehabilitation. *CEUR Workshop Proceedings*, *3501*, 140–157. https://ceur-ws.org/Vol-3501/s50.pdf

Palagin, O., Kaverinsky, V., Litvin, A., & Malakhov, K. (2023). OntoChatGPT information system: Ontology-driven structured prompts for ChatGPT meta-learning. *International Journal of Computing*, *22*(2), 170–183. https://doi.org/10.47839/ijc.22.2.3086

Palagin, O., Malakhov, K., Velychko, V., & Semykopna, T. (2022). Hybrid e-rehabilitation services: SMART-system for remote support of rehabilitation activities and services. *International Journal of Telerehabilitation, Special Issue* (Research Status Report – Ukraine). https://doi.org/10.5195/ijt.2022.6480

Palagin, O., Petrenko, M., Velychko, V., & Malakhov, K. (2014). Development of formal models, algorithms, procedures, engineering and functioning of the software system "Instrumental complex for ontological engineering purpose". *CEUR Workshop Proceedings*, *1843*, 221–232. http://ceur-ws.org/Vol-1843/221-232.pdf

Palagin, O., Velychko, V., Malakhov, K., & Shchurov, O. (2018). Research and development workstation environment: The new class of current research information systems. *CEUR Workshop Proceedings*, *2139*, 255–269. http://ceur-ws.org/Vol-2139/255-269.pdf

Quamar, A., Lei, C., Miller, D., Ozcan, F., Kreulen, J., Moore, R. J., & Efthymiou, V. (2020). An ontology-based conversation system for knowledge bases. *Proceedings of the 2020 ACM SIGMOD International Conference on Management of Data*, 361–376. https://doi.org/10.1145/3318464.3386139

Quamar, A., Özcan, F., Miller, D., Moore, R. J., Niehus, R., & Kreulen, J. (2020). Conversational BI: An ontology-driven conversation system for business intelligence applications. *Proceedings of the VLDB Endowment*, *13*(12), 3369–3381. https://doi.org/10.14778/3415478.3415557

Stetsyuk, P. I., Fischer, A., & Khomiak, O. M. (2023). Unified representation of the classical ellipsoid method. *Cybernetics and Systems Analysis*, *59*(5), 784–793. https://doi.org/10.1007/s10559-023-00614-x

SACJ 35(2) December 2023
Viewpoint

Ontology-Driven Computer Systems: Elementary Senses in Domain Knowledge Processing

Mykola Petrenko[a], Ellen Cohn[b], Oleksandr Shchurov[a], Kyrylo Malakhov[a]

[a] Microprocessor technology lab, Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine
[b] Department of Communication and Rhetoric, University of Pittsburgh, Pittsburgh, PA, USA

ABSTRACT
This article delves into the evolving frontier of ontology-driven natural language information processing. Through an in-depth examination, we put forth a novel linguistic processor architecture, uniquely integrating linguistic and ontological paradigms during semantic analysis. Distancing from conventional methodologies, our approach showcases a profound merger of knowledge extraction and representation techniques. A central highlight of our research is the development of an ontology-driven information system, architected with an innate emphasis on self-enhancement and adaptability. The system's salient capability lies in its adept handling of elementary knowledge, combined with its dynamic aptitude to foster innovative concepts and relationships. A particular focus is accorded to the system's application in scientific information processing, signifying its potential in revolutionising knowledge-based applications within scientific domains. Through our endeavours, we aim to pave the way for more intuitive, precise, and expansive ontology-driven tools in the realm of knowledge extraction and representation.

Keywords Ontology engineering, Elementary sense, Knowledge representation, Commonsense knowledge, Deep artificial intelligence, Scientific model of the World

Categories • **Artificial intelligence** ∼ **Knowledge representation and reasoning, Ontology engineering**

Email
Mykola Petrenko – petrng@ukr.net,
Ellen Cohn – ecohn@pitt.edu,
Oleksandr Shchurov – alexlug89@gmail.com,
Kyrylo Malakhov – malakhovks@nas.gov.ua (CORRESPONDING)

1 INTRODUCTION

The development of dynamic computerised knowledge systems and deep artificial intelligence systems are intertwined, stemming from similar foundational roots. A core aim for these systems is formulating a comprehensive scientific model of the world (SMW) and harnessing it effectively. The former systems strive to weave a global web of trans-disciplinary knowledge,

Petrenko, M., Cohn, E., Shchurov, O., and Malakhov, K. (2023). Ontology-Driven Computer Systems: Elementary Senses in Domain Knowledge Processing [Viewpoint]. *South African Computer Journal* 35(2), 127–144. https://doi.org/10.18489/sacj.v35i2.17445

ISSN 1015-7999 (print) ISSN 2313-7835 (online)

targeting humanity's intricate challenges, while the latter seeks to emulate human-like common sense and a comprehensive world view.

The ambition to attain human-level artificial intelligence (AI) remains a foremost aspiration within AI research. Such an achievement could lead to revolutionary innovations with far-reaching consequences for mankind. Currently, however, AI's role is predominantly as a practical instrument with specific, albeit limited, applications.

As AI systems tailored for real-world challenges evolve, they will undeniably benefit from contemporary research breakthroughs. It is anticipated that, in the near future, AI's potential will predominantly be showcased through a surge in specialised applications. This trajectory is already evident across sectors, from industry to economics to societal facets. The expansive promise of AI is evident, as it permeates diverse fields, from scientific endeavours to facilitation of major tech innovations (Ford, 2021; Luger, 2008; OpenAI, 2023).

Reference to David Ferrucci's perspective on deep artificial intelligence is apt here. The CEO and founder of the AI startup, Elemental Cognition, postulates that mastering natural language understanding is pivotal for achieving universal intelligence. Contrasting with approaches like those by DeepMind that probe brain physiology, Ferrucci's stance is on building a system surpassing human capabilities in natural language processing and logical reasoning. He uniquely contends that the foundational elements for crafting such intelligence are already available (Ford, 2018).

To achieve this vision, Elemental Cognition is devising a hybrid system. This model synergises deep neural networks and varied machine learning strategies with software modules honed for logic and reasoning, all rooted in conventional programming paradigms. Interestingly, the current research climate favours an amalgamation, rather than a division, between symbolist and connectionist systems. Such an integrated research avenue is termed "neurosymbolic AI" (Ford, 2018, 2021).

Understanding causality is crucial for fostering creativity and devising alternative solutions. Unlike reinforcement learning algorithms in neural networks that necessitate repeated failures for successful strategising, humans inherently practice mental simulations. This cognitive act allows us to predict potential outcomes of varying decisions, rooted in our intrinsic grasp of causality. This facilitates our quest for answers to the quintessential "why?" Mastery over causality, especially the skill to frame and tackle causative questions, is integral to the evolution of universal machine intelligence (Ford, 2018).

A distinguishing trait of human intelligence is the ability to assimilate information from one source and adapt it across different realms, underpinning creativity and innovation. For universal machine intelligence to be practically impactful, it must go beyond mere textual understanding. Its true merit rests in its capability to leverage its knowledge reservoir to navigate uncharted challenges. An AI system's proficiency in applying knowledge in diverse and novel scenarios might very well be the definitive benchmark for gauging its intellectual depth (Ford, 2021).

Echoing D. Ferrucci's sentiment, the capacity to extrapolate information from one context and adeptly apply it in varied scenarios is quintessential for fostering innovation (Ford, 2018).

https://doi.org/10.18489/sacj.v35i2.17445

From our vantage point, emulating human reasoning in deep artificial intelligence requires formulating a domain-specific SMW or, minimally, a discipline-oriented SMW. Constructing such a model should be anchored in an ontological methodology, culminating in a Scientific-Ontological Model of the World (SOMW). The ensuing discourse will explore the imperative of crafting and leveraging the SOMW, underscoring the pivotal role of systematic ontological knowledge representation in replicating human reasoning via deep artificial intelligence.

Ontology-driven information processing and knowledge representation originated from the quest for a standard protocol to streamline knowledge across varied knowledge spectra. This paradigm aims to offer a unified blueprint and guiding principles for systematic knowledge depiction, categorisation, and interlinking, irrespective of the domain of expertise. The advent of ontological strategies has enabled the effective construction of knowledge-centric systems and, crucially, laid the foundation for trans-disciplinary engagement and ontological engineering within the realm of contemporary AI (Gómez-Pérez et al., 2004; Guarino, 1998; Palagin, Kaverinskiy et al., 2023; Sowa, 2000; Staab & Studer, 2009).

2 ONTOLOGICAL COMPONENTS AND KNOWLEDGE REPRESENTATION

Ontology, as a formalised structure for knowledge representation, is typically defined by the following four components:

Classes – These symbolise categories or concepts within a specific domain, offering a means to group entities sharing similar attributes.

Properties – These delineate attributes or associations of classes and individuals, serving to establish relationships with terms such as “has”, “is”, or “part of”.

Individuals – Representing tangible instances of classes, individuals can be thought of as distinct entities, concepts, or cases within a domain.

Axioms or Constraints – These constitute rules or logical assertions that dictate relationships and behaviour within an ontology, reinforcing its logical consistency.

These components underpin ontology modelling, offering a robust framework for structured knowledge representation specific to a domain. Such a structure not only aids human comprehension but also facilitates machine-based reasoning (Palagin, Petrenko et al., 2023).

Ontological methodologies grant users a holistic perspective on specific subjects or intricate projects. Utilising ontological models enables the delineation of classes, entities, functions, and formal theories. Ontological tools support the creation of analytic systems for research and organisational purposes, which span functions from multi-factorial analysis of primary data to fostering collaborative decision-making. Moreover, ontologies serve as both the manipulative medium and outcome for Semantic Web technologies.

An invaluable tool within the ontological suite is the linguistic-ontological model of the world (LOMW). Envisioned as a lexicographical system, the LOMW is an integral part of the

https://doi.org/10.18489/sacj.v35i2.17445

overarching scientific model of the world (SMW) and is pivotal for systems focused on natural language object comprehension (Palagin, 2006, 2016; Palagin, Petrenko et al., 2023).

Within this framework, the LOMW acts as a categorical scaffold, providing a semantically enriched base for domain-specific knowledge repositories. It also aids in merging diverse knowledge sources. By amalgamating linguistic and ontological components, the LOMW enhances comprehension, communication, and knowledge management, propelling both domain-specific and interdisciplinary research.

Whether it is a human's linguistic cognition or a computer system, the processing of speech or textual data hinges on a linguistic processor. Within a computer system, this processor is paramount, responsible for discerning and understanding incoming natural language data, deriving core knowledge, and presenting it in a logical format.

This processed data lays the groundwork for knowledge-based operations, aiding in problem resolution, decision-making, and various associated tasks. Essentially, the computer system linguistic processor serves as a conduit between human linguistic input and computational action, extracting and harnessing knowledge for diverse applications.

A linguistic processor, either hardware or software-based, deciphers textual data, such as a document, article, monograph, or linguistic corpus of texts, through consecutive stages of linguistic examination. This typically encompasses graphematical, morphological, syntactic, and surface-semantic evaluations, each contributing to the understanding of the structure and semantics of text (Kurgaev & Petrenko, 1995; Petrenko & Kurgaev, 2003; Petrenko & Sofiyuk, 2003).

Post-processing by the linguistic processor, the resultant information structure is primed for intensive semantic scrutiny within an extra-linguistic subsystem. Here, the primary goal is concept structuring. Essentially, it automates knowledge extraction from the natural language object, aiming to pragmatically interpret this knowledge, mirroring human understanding and response (Palagin, Petrenko et al., 2023).

The Analytical and Understanding System (AUS) architecture, with the LOMW at its core, is illustrated in Figure 1. The AUS's primary data reservoir is the corpus of text, linked to a specific knowledge domain or an array of scientific writings. The linguistic corpus, a finite text set, is represented by k, which denotes the collective number of texts in the corpus. These texts are processed sequentially, channelled initially through the graphematical analysis subsystem.

As the text progresses through the linguistic analysis algorithm, it metamorphoses across graphematical, morphological, syntactic, and semantic structures, each possessing distinct representation models and tools. An exhaustive account of this procedure is elaborated in Palagin, Petrenko et al. (2023). What differentiates this method from traditional semantic analysis is the integration of the linguistic-ontological picture of the world within the semantic review. This picture transcends dictionary-based semantic data, embedding multi-tiered patterns of both general and specific semantic structures observed in elementary sentences.

Upon completing the AUS processing, a text-sentence pattern table emerges. This repository encompasses the information structure for the entire text, serving as input for the extra-linguistic text processing subsystem. Within this subsystem, formal-logical translation of the

https://doi.org/10.18489/sacj.v35i2.17445

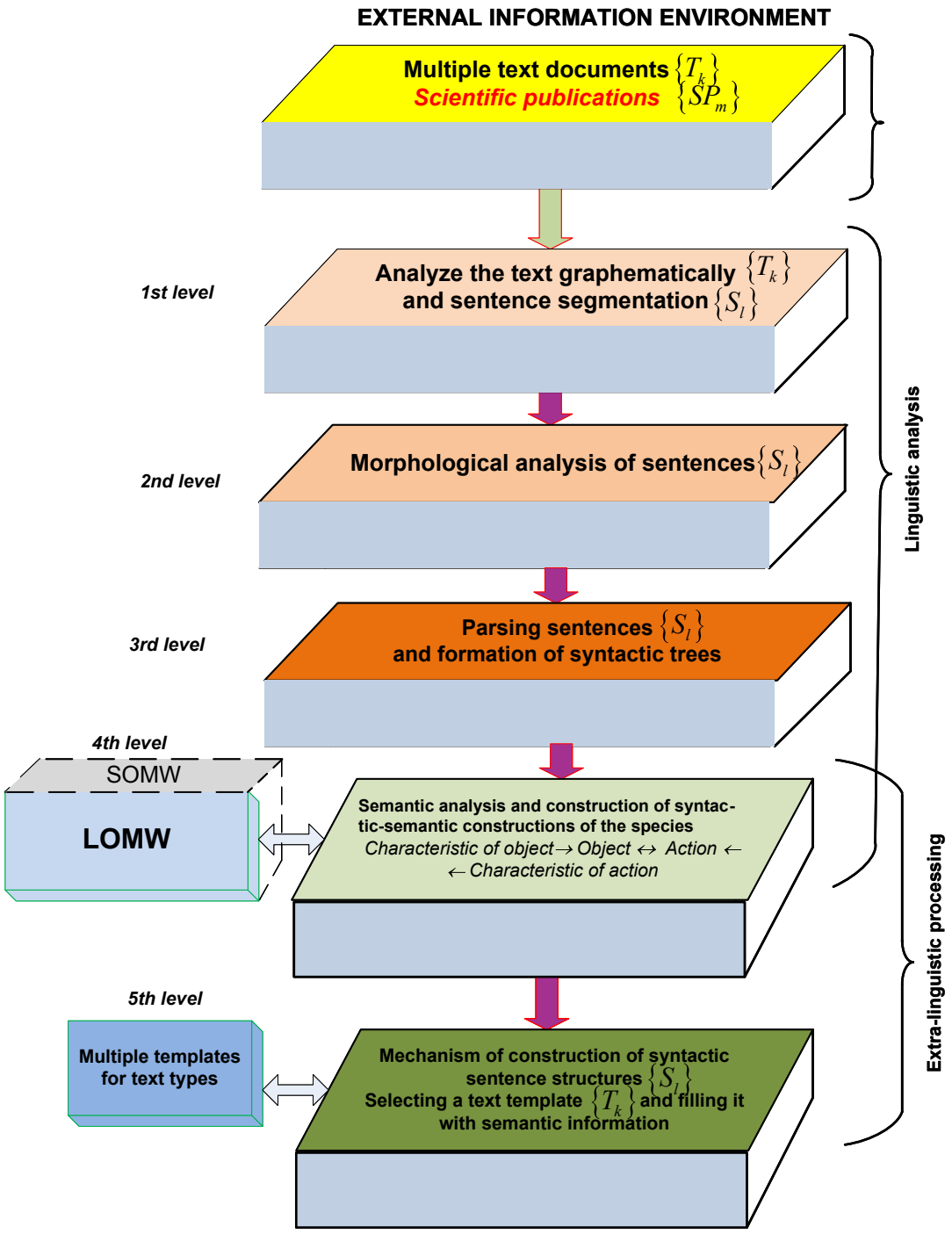


Figure 1: The Analytical and Understanding System architecture [a]

[a]Palagin, Petrenko et al. (2023)

https://doi.org/10.18489/sacj.v35i2.17445

sentences and the collective text is executed, typically transforming the text into an appropriate first-order formal theory. A common technique includes an intermediary phase where data is recast into modified conceptual graphs, followed by a transition into first-order predicate logic (Palagin, Kaverinskiy et al., 2023).

The LOMW's formulation is exhaustively dissected in Palagin (2016), and Palagin (2006) furnishes intricate details about the SOMW's development. Both are indispensable references, shedding light on the methodologies integral to the creation of these vital knowledge representation and semantic analysis system components.

3 TEMPORAL AND SPATIAL DYNAMICS OF KNOWLEDGE DEVELOPMENT

Knowledge evolution within any domain, including the expansive realm of science, manifests as parameters that are temporally and spatially modulated. Historically, the pace of knowledge accumulation in nascent stages of scientific development, both broadly and within particular specialisations, paled in comparison to current exponential knowledge growth rates. While knowledge quantity and its informational representation are interlinked, they are not synonymous. Their association, at any temporal juncture, hinges largely on the equilibrium between verbal and formalised representations. The latter, which includes analytical, tabular, and graphical representations, offers brevity compared to its verbal counterpart and is more amenable to operational handling. Over time, three primary evolutionary trajectories are discerned (Palagin, 2006):

1. Augmentation in total knowledge and information
2. Expansion of the formalised knowledge segment
3. Super-session of antiquated knowledge with contemporary insights

A salient characteristic of generic knowledge evolution is the presence of dichotomous tendencies: scientific discipline differentiation followed by integration. Historically, the primacy lay with differentiation, leading to the genesis of specialised disciplines. Presently, differentiation coexists with integration, symbolised by the emergence of multidisciplinary research entities and the inception of trans-disciplinary convergence clusters. These clusters are instrumental, acting as crucibles for cross-disciplinary collaboration, thereby furthering cohesive solutions to multifaceted challenges and promoting human epistemological advancement (Palagin, Petrenko et al., 2023).

4 ONTOLOGICAL KNOWLEDGE-BASED SYSTEMS IN COMPUTER SCIENCE

The advancement of blueprints and methodologies catering to knowledge-based systems remains a focal endeavour within computer science. The genesis of ontological knowledge-based systems (OKBSs) is intrinsically woven with the maturation of theoretical foundations and design approaches.

https://doi.org/10.18489/sacj.v35i2.17445

Integral elements include:

Generalised system architecture and structure – This involves the articulation of rudimentary principles governing system architecture, ensuring a cohesive framework for knowledge representation and processing.

Formal knowledge representation models – This aspect emphasises structured knowledge representation models, promoting efficient data stewardship and retrieval.

Algorithms for knowledge processing – This pertains to the creation of algorithms facilitating structured knowledge handling, supporting a gamut of knowledge-centric operations.

Collectively, these design endeavours amplify the significance of ontological knowledge within knowledge-based systems, specifically when addressing formidable objectives such as crafting a SOMW. As underscored earlier, the SOMW is integral to deep AI and the burgeoning "neurosymbolic" AI domain. Both strive for an amalgamation of symbolic and connectionist AI paradigms, aiming for a more intricate AI embodiment.

An evolving intelligent computer system's architectural development can be viewed from a bifocal lens, capturing both external (user-centric) and intrinsic dimensions. The harmonious orchestration between these dimensions is quintessential for maximising the efficacy of OKBSs (Palagin, 2006).

Architecting efficacious ontologically governed computer systems necessitates the assimilation of modern computer science realms, inclusive of artificial intelligence, knowledge processing, and the pragmatic model of linguistic consciousness. Conceptualised as a productive sequence, their operational synergy mirrors: "Input signal → Knowledge System → Reaction."

An emerging OKBS functions with pre-ordained goals, spanning both long-term visions and immediate targets. This operational alignment is modulated by feedback-driven interactions with the external data milieu. Central to an OKBS's operational tenet is its knowledge system, envisioned as an intricate subsystem synergising with a constellation of domain-specific knowledge subsystems (Palagin, Petrenko et al., 2023; Palagin et al., 2014; Palagin et al., 2018). This multifaceted interplay equips the OKBS to adeptly ingest, process, and apply knowledge spanning varied domains, resonating with its operational objectives.

Intrinsically, the OKBS capitalises on its knowledge system and specialised knowledge subsystems, dynamically fine-tuning its reactions to match overarching goals and the capricious demands of the external information ecosystem. This adaptability ensures the sustained efficacy of the system in fulfilling its delineated objectives.

The OKBS architecture, visualised in Figure 2, spotlights a pivotal component: the self-evolving mechanism of the knowledge base (KB) pertinent to a designated domain. This auto-evolutionary feature ensures the KB's continuous adaptation and growth, resonating with the domain's shifting contours and insights.

https://doi.org/10.18489/sacj.v35i2.17445

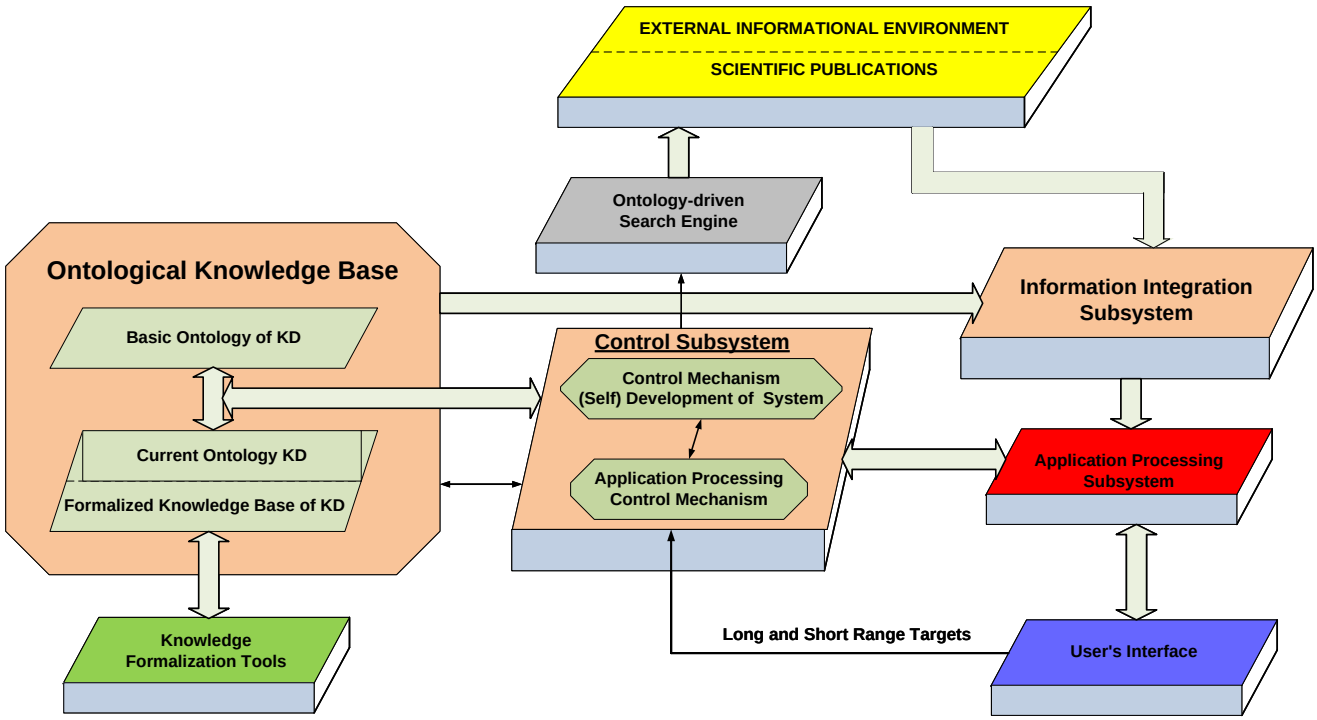


Figure 2: The Ontological Knowledge-Based System architecture

Central to this self-propagating mechanism are ontological controls governing two foundational processes: external information space exploration and formalised knowledge base formation, which materialises via two predominant channels (Palagin, 2006, 2016):

1. Data extraction from the External Information Environment (predominantly the Internet).

2. Inference-driven knowledge genesis.

Both facets of formalised KB evolution within ontological knowledge-based systems exhibit profound interplay. Fresh knowledge genesis via inferential channels is contingent upon the influx of contemporary data, predominantly sourced from the digital universe of the Internet. This perpetual data stream equips the system with foundational insights, crucial for logical derivations, inferential processes, and the proactive birth of new knowledge realms.

Furthermore, the ontological addition of novel knowledge, potentially introducing new concepts, is integral for knowledge base evolution. This entails identifying and assimilating emerging concepts and dynamics from external information spheres into the system's ontology. This dynamic integration approach accentuates the imperativeness of a cyclic knowledge procurement methodology, ensuring the OKBS's perpetual adaptation and absorption of evolving ontological insights (Kryvyi, 2016).

https://doi.org/10.18489/sacj.v35i2.17445

5 FORMALISING SCIENTIFIC PUBLICATIONS FOR KNOWLEDGE DEVELOPMENT

Scientific publications serve as prominent vehicles for the synthesis of new knowledge, especially given their unique scientific narrative style and structured presentation. Scientific publications inherently possess a well-defined syntactic and semantic structure. Their templated format allows for automated formalised description of content, a pivotal characteristic elucidated in (Malakhov et al., 2023).

In the developmental mode, the OKBS processes user queries directed towards the natural language processing (NLP) database, as detailed in Malakhov et al. (2023).

The ontology system for processing and enhancing scientific publications is visually summarised in Figure 3, offering a schematic of primary components and functions.

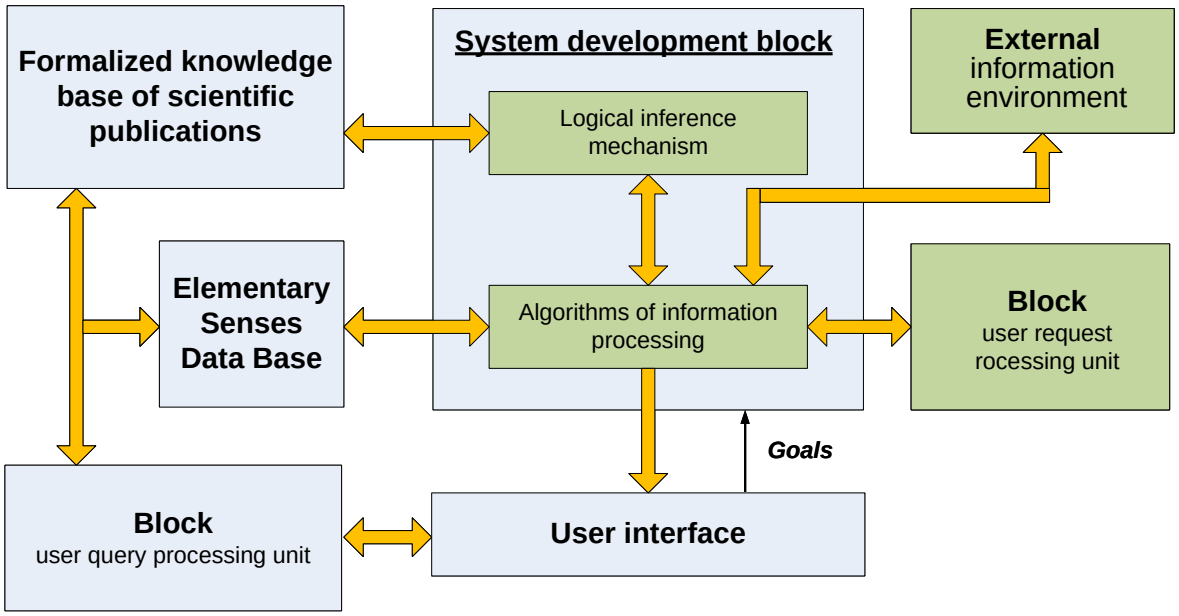


Figure 3: The architecture of the ontology system for processing and enhancing scientific publications

Ontology system development is characterised by three distinct operational modalities:

1. **Logical inference mechanism**: This mode employs reasoning tools like Pellet's reasoner, enhancing knowledge through inferential techniques. It crafts novel ontological connections and unveils nuanced relationships within the pre-existing knowledge base.

2. **Elementary sense (ES) processing algorithms**: This mode harnesses specialised algorithms tailored for elementary sense analysis. The "electronic collider" operation (Malakhov et al., 2023), exemplifies this approach. By dissecting foundational linguistic and semantic units, knowledge is extracted directly from elementary sense analysis.

https://doi.org/10.18489/sacj.v35i2.17445

3. **Formula-driven NLP**: Employing recognised formulas, such as the Brooks formula, underscores behaviour-centric strategies for natural language comprehension.

Selecting an approach may hinge on the system's strategic objectives, domain intricacies, and specific knowledge development aims. With the amalgamation of inferential, algorithmic, and formulaic methods, the ontology system exhibits versatility in knowledge development tasks, progressively honing its acumen.

We now investigate the correlation between *elementary sense*, *commonsense knowledge*, and *commonsense reasoning* in ontology-driven computer systems and domain knowledge processing.

Definitions

The *elementary sense* notion, introduced in Malakhov et al. (2023): a simple two-syllable statement that contains a subject, a predicate, and a direct object. These components correspond to the subject, predicate, and object of the Semantic Web RDF-triple.

The *commonsense knowledge* notion, introduced in Davis (1990): the universal understanding about the world possessed by most individuals, encompassing obvious inferences and covering a vast range of domains from natural language to high-level vision. It forms the fundamental core of human knowledge and intelligence.

The *commonsense reasoning* notion, introduced in Davis; Mueller (1990, 2015): the act of performing inference on a set of object-level information using a knowledge base and a knowledge base manager. It involves deriving new insights from existing knowledge about general worldly scenarios.

Similarities

Basis for knowledge representation – Both "Elementary Sense" and "Commonsense Knowledge" provide foundational structures for representing information. Elementary Sense offers a concise, structured format analogous to Semantic Web RDF-triples, while Commonsense Knowledge provides a comprehensive knowledge about the world.

Inference –Both Commonsense Knowledge and Commonsense Reasoning involve the process of making inferences. While the former provides the foundational knowledge, the latter is about the actual process of deriving new insights from that knowledge. Furthermore, with Elementary Sense, inference can also be performed using SPARQL queries on RDF-triples, thereby extracting precise insights from the structured data representation.

Dynamic Understanding – All three concepts emphasise the dynamic nature of knowledge. Elementary Senses offer structured representations, Commonsense Knowledge encompasses ever-growing human understanding, and Commonsense Reasoning involves the continual process of deriving new insights.

https://doi.org/10.18489/sacj.v35i2.17445

Differences

Granularity – Elementary Sense focuses on a precise representation of information as simple two-syllable statements, aligned with RDF-triples, while Commonsense Knowledge is broader, spanning a wide array of general knowledge domains.

Purpose – The primary goal of Elementary Sense is to offer structured representations for easy processing. In contrast, Commonsense Knowledge serves as a foundational base for understanding the world, and Commonsense Reasoning seeks to infer new insights based on that foundational knowledge.

Process vs. Data – Elementary Sense is about data representation and storage, aligning closely with Semantic Web structures. Commonsense Knowledge, on the other hand, is about the data itself, and Commonsense Reasoning is process-oriented, centred on the act of inference.

Extracting New Knowledge from Existing Knowledge

Role of Elementary Sense – In ontology-driven computer systems, Elementary Sense plays a crucial role in simplifying and structuring data. By organising information in a format analogous to RDF-triples, it aids in knowledge extraction, paving the way for deeper semantic and ontological analysis.

Incorporating Commonsense – Commonsense Knowledge acts as a background reservoir during knowledge processing. When systems encounter ambiguous or incomplete data, this knowledge can be leveraged to fill in gaps or infer missing components. The vast scope of Commonsense Knowledge ensures a well-rounded understanding, even in the absence of explicit information.

Reasoning and Evolution – Through Commonsense Reasoning, systems can derive new information or connections from existing knowledge. Applying inference on a knowledge base, especially when combined with the structured insights from Elementary Senses and SPARQL queries on RDF-triples, magnifies the potential for discovering new patterns, relationships, or insights. This dynamic reasoning is pivotal for the evolution and self-improvement of ontology-driven computer systems.

5.1 Connections

Elementary Sense, Commonsense Knowledge, and Commonsense Reasoning are integrally connected in the realm of ontology-driven computer systems and domain knowledge processing. Together, they contribute to the accurate representation, comprehensive understanding, and dynamic expansion of knowledge within the system.

https://doi.org/10.18489/sacj.v35i2.17445

ESs are pivotal for scientific publications analysis. To elaborate:

Scientific publications repository – This encompasses a myriad of structured scientific articles, replete with titles, bibliographic details, texts (structured as sections, paragraphs, sentences, inclusive of figures, formulas, and tables), abstracts, preludes, conclusions, and citations.

Complex sentence decomposition – Intricate sentence structures are distilled into simpler, ideally binary, constructs to streamline analysis.

Simple sentence depiction – Binary sentences are decomposed into their foundational triad: subject, predicate, and complement, analogous to the subject-predicate-object (SPO) or RDF-triples, prevalent in Semantic Web frameworks.

Segmenting intricate constructs into *Elementary Senses* encapsulated as RDF-triples ensures concise knowledge representation. Consequently, this fosters efficient and pinpoint analysis and extraction of knowledge nuances from scientific publications.

On average, a sentence in a scientific publication text, particularly in Ukrainian, may encapsulate 3 to 4 ESs. The manipulation of these elementary meanings, combined with the associated ontological knowledge domain structures, paves the way for the potential genesis of new ontological concepts or inter-relationships.

Example to illustrate the ES formation process

In the example below, the following abbreviations are employed:

S – ES subject

P – ES predicate

O – ES object

Cnt ES*m* – context of the *m*th elementary sense

Y*n-j* – where *n* signifies the level number in the context ontograph, and *j* indicates the ordinal number of the concept node at that specific level.

Original Statement – "Theory and practice of creation and use of knowledge-based systems is the most actual and intensively developing direction of Computer Science, allowing increasing the efficiency of creation and use of computer technologies, application systems and toolkits."

Upon decomposition into ES, the sentence bifurcates into its core components: subject, predicate, and object, alongside the contextual codes of the knowledge domain (KD):

- **ES1** Computer Science is the most actual and intensively developing direction;

  S – Computer Science, **P** – have, **O** – actual and intensively developing direction;

  Cnt ES*m* – **Y7-5**, **Y9-5**.

https://doi.org/10.18489/sacj.v35i2.17445

- **ES2** Direction of Computer Science is theory and practice of creation and use of systems;

  S – Direction of Computer Science, **P** – to be, **O** – theory and practice of creation and use of systems;

  Cnt ES*m* – **Y7-5**, **Y9-5**.

- **ES3** Systems is knowledge-based systems;

  S – Systems, **P** – to be, **O** – systems of knowledge-based systems;

  Cnt ES*m* – **Y7-5**, **Y9-3**, **Y9-5**.

- **ES4** Knowledge-based systems allow for an increase the efficiency of creation and use of computer technologies;

  S – Knowledge-based systems, **P** – to allow for an increase, **O** – the efficiency of creation and use of computer technologies;

  Cnt ES*m* – **Y7-5**, **Y9-5**.

- **ES5** Knowledge-based systems allow for an increase the efficiency of creation and use of application systems;

  S – Knowledge-based systems, **P** – to allow for an increase, **O** – the efficiency of creation and use of application systems;

  Cnt ES*m* – **Y7-5**, **Y10-6**.

- **ES6** Knowledge-based systems allow for an increase the efficiency of creation and use of toolkits;

  S – Knowledge-based systems, **P** – to allow for an increase, **O** – the efficiency of creation and use of toolkits;

  Cnt ES*m* – **Y7-5**, **Y10-4**.

A segment of the context ontograph is visually represented in Figure 4. It should be noted that during the analysis of ES structural components, the ontograph of contexts pertaining to the knowledge domain is extensively utilised. This ensures a precise association with the respective knowledge domain. Within this framework, an ES combined with its specific context is termed *Elementary knowledge*.

https://doi.org/10.18489/sacj.v35i2.17445

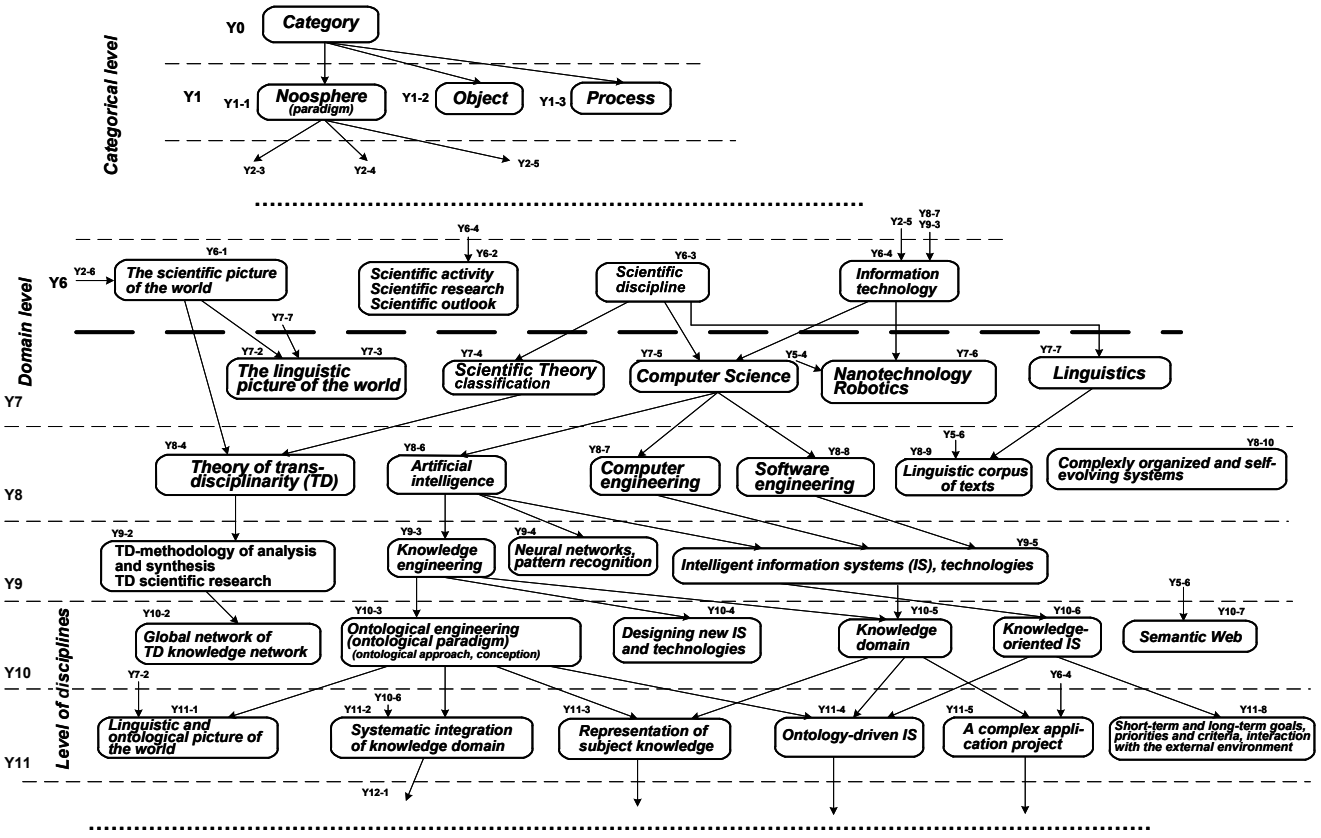


Figure 4: The fragment of the contexts ontograph

6 CONCLUSION

In this research, we have delved deep into the intersection of ontological perspectives and natural language processing to revolutionise the way knowledge is extracted and represented. By presenting a groundbreaking architecture for a linguistic processor, we have shifted away from traditional implementations, bringing together linguistic and ontological facets during the semantic analysis phase. Moreover, our venture into constructing a forward-thinking, ontology-driven information system is marked by its inherent emphasis on continuous self-enhancement. A standout feature of our approach is the enhancement of the ontological system, tailored explicitly for scientific data processing. This system's prowess not only lies in its adept handling of elementary knowledge but also its dynamic capability to birth new concepts and weave intricate relationships. Such advancements hold immense promise in bolstering the effectiveness and relevance of our system in a myriad of scientific domains, marking a significant stride in the landscape of knowledge representation and analysis.

https://doi.org/10.18489/sacj.v35i2.17445

7 CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mykola Petrenko: Supervision, Conceptualisation, Methodology, Writing – original draft, Validation. *Ellen Cohn*: Writing – review & editing. *Oleksandr Shchurov*: Writing – original draft. *Kyrylo Malakhov*: Validation, Resources, Term, Writing – review & editing.

8 ACKNOWLEDGEMENTS

The research team at the Microprocessor Technology Lab extends its gratitude to Oleksandr Palagin, a distinguished scholar and leader in the field. Oleksandr Palagin, who holds the esteemed titles of Academician of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences, Professor, Honored Inventor of Ukraine, Deputy Director for Research at the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine, and Head of the Microprocessor Technology Lab, served as the guiding force and scientific supervisor for this research endeavor. We deeply appreciate his invaluable mentorship and expertise throughout this project.

The corresponding author, Kyrylo Malakhov, representing both himself and his co-author, Mykola Petrenko, along with Oleksandr Shchurov, would like to express their heartfelt gratitude to Dr. Ellen Cohn (PhD, CCC-SLP, ASHA-F) from the Department of Communication at the University of Pittsburgh, PA, USA. Dr. Cohn provided invaluable assistance in reviewing and editing the article, and her international support has played a pivotal role in preserving Ukrainian science during wartime and enhancing international scientific collaboration.

The Glushkov Institute of Cybernetics research team wishes to extend a special acknowledgment to Katherine Malan, the Editor-in-Chief of the South African Computer Journal. We deeply value her commitment to advancing Ukrainian science by facilitating the publication of research in scholarly journals, which has significantly contributed to our field's progress.

9 FUNDING

This study would not have been possible without the financial support of the National Research Foundation of Ukraine (Open Funder Registry: 10.13039/100018227). Our work was funded by Grant contract (application ID: 2021.01/0136):

> *Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modeling* (Malakhov, 2022, 2023a, 2023b; Palagin, Malakhov, Velychko, Semykopna & Shchurov, 2022; Palagin, Malakhov, Velychko & Semykopna, 2022; Stetsyuk et al., 2023).

10 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.

References

Davis, E. (1990, January). Chapter 1 – Automating common sense. In *Representations of commonsense knowledge* (pp. 1–26). Morgan Kaufmann. https://doi.org/10.1016/B978-1-4832-0770-4.50009-5

Ford, M. (2018, November). *Architects of intelligence: The truth about AI from the people building it.* Packt Publishing.

Ford, M. (2021, September). *Rule of the robots: How artificial intelligence will transform everything* (First Edition). Basic Books.

Gómez-Pérez, A., Fernández-López, M., & Corcho, O. (2004). *Ontological engineering* (1st ed.). Springer-Verlag. https://doi.org/10.1007/b97353

Guarino, N. (1998, June). *Formal ontology in information systems: Proceedings of the 1st international conference June 6-8, 1998, trento, italy*. IOS Press.

Kryvyi, S. (2016). Formal ontological models in scientific researchers. *Upravlâûŝie sistemy i mašiny*, *263*(3), 04–15. https://doi.org/10.15407/usim.2016.03.004

Kurgaev, A. F., & Petrenko, M. G. (1995). Processor structure design. *Cybernetics and Systems Analysis*, *31*(4), 618–625. https://doi.org/10.1007/BF02366417

Luger, G. (2008, February). *Artificial intelligence: Structures and strategies for complex problem solving* (6th edition). Pearson.

Malakhov, K. (2022). Letter to the editor – Update from Ukraine: Rehabilitation and research. *International Journal of Telerehabilitation*, *14*(2), 1–2. https://doi.org/10.5195/ijt.2022.6535

Malakhov, K. (2023a). Insight into the digital health system of Ukraine (ehealth): Trends, definitions, standards, and legislative revisions. *International Journal of Telerehabilitation*, *15*(2). https://doi.org/10.5195/ijt.2023.6599

Malakhov, K. (2023b). Letter to the editor – Update from Ukraine: Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modeling. *International Journal of Telerehabilitation*, *15*(1). https://doi.org/10.5195/ijt.2023.6562

Malakhov, K., Petrenko, M., & Cohn, E. (2023). Developing an ontology-based system for semantic processing of scientific digital libraries. *South African Computer Journal*, *35*(1), 19–36. https://doi.org/10.18489/sacj.v35i1.1219

Mueller, E. T. (2015, January). Chapter 1 - Introduction. In *Commonsense reasoning* (2nd ed., pp. 1–16). Morgan Kaufmann. https://doi.org/10.1016/B978-0-12-801416-5.00001-2

OpenAI. (2023, March). *GPT-4 technical report* (tech. rep.) (arXiv:2303.08774 [cs]). OpenAI. arXiv. https://doi.org/10.48550/arXiv.2303.08774

Palagin, O., Malakhov, K., Velychko, V., Semykopna, T., & Shchurov, O. (2022). Hospital information smart-system for hybrid e-rehabilitation. *CEUR Workshop Proceedings*, *3501*, 140–157. https://ceur-ws.org/Vol-3501/s50.pdf

Palagin, O. (2006). Architecture of ontology-controlled computer systems. *Cybernetics and Systems Analysis*, *42*(2), 254–264. https://doi.org/10.1007/s10559-006-0061-z

Palagin, O. (2016). An ontological conception of informatization of scientific investigations. *Cybernetics and Systems Analysis*, *52*(1), 1–7. https://doi.org/10.1007/s10559-016-9793-6

Palagin, O., Kaverinskiy, V., Litvin, A., & Malakhov, K. (2023). OntoChatGPT information system: Ontology-driven structured prompts for ChatGPT meta-learning. *International Journal of Computing*, *22*(2), 170–183. https://doi.org/10.47839/ijc.22.2.3086

Palagin, O., Malakhov, K., Velychko, V., & Semykopna, T. (2022). Hybrid e-rehabilitation services: SMART-system for remote support of rehabilitation activities and services. *International Journal of Telerehabilitation*, *Special Issue*(Research Status Report – Ukraine). https://doi.org/10.5195/ijt.2022.6480

Palagin, O., Petrenko, M., Kryvyi, S., Boyko, M., & Malakhov, K. (2023, July). *Ontology-driven processing of transdisciplinary domain knowledge*. Iowa State University Digital Press. https://doi.org/10.31274/isudp.2023.140

Palagin, O., Petrenko, M., Velychko, V., & Malakhov, K. (2014). Development of formal models, algorithms, procedures, engineering and functioning of the software system "Instrumental complex for ontological engineering purpose". *CEUR Workshop Proceedings*, *1843*, 221–232. http://ceur-ws.org/Vol-1843/221-232.pdf

Palagin, O., Velychko, V., Malakhov, K., & Shchurov, O. (2018). Research and development workstation environment: The new class of current research information systems. *CEUR Workshop Proceedings*, *2139*, 255–269. http://ceur-ws.org/Vol-2139/255-269.pdf

Petrenko, M., & Kurgaev, A. (2003). Distinguishing features of design of a modern circuitry type processor. *Upravlyayushchie Sistemy i Mashiny*, *187*(5), 16–19. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0347622333&partnerID=40&md5=7283307afdf891445ec9062c7b2ff80a

Petrenko, M., & Sofiyuk, A. (2003). On one approach to the transfer of an information structures interpreter to PLD-implementation. *Upravlyayushchie Sistemy i Mashiny*, *188*(6), 48–57. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0442276898&partnerID=40&md5=44974b40409363e5fe4378e240149c52

Sowa, J. F. (2000, January). *Knowledge representation: Logical, philosophical, and computational foundations* (1st ed.). Brooks / Cole.

Staab, S., & Studer, R. (Eds.). (2009). *Handbook on ontologies* (2nd ed.). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-92673-3

Stetsyuk, P. I., Fischer, A., & Khomiak, O. M. (2023). Unified representation of the classical ellipsoid method. *Cybernetics and Systems Analysis*, *59*(5), 784–793. https://doi.org/10.1007/s10559-023-00614-x