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South African Computer Journal

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- The article should start as follows:
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- *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

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- the paper includes at least 30% new material

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

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Editorial: Winter 2024 Update

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

SACJ editorial team

In the last year, Martin Olivier and Maureen Tanner resigned as associate editors, but we are pleased to announce that four new associate editors have joined the editorial team (Marijke Coetzee, Aurona Gerber, Tendani Mawela, and Terence van Zyl). Ian Sanders has moved into the role of assistant editor to take care of the copyediting of manuscripts before publication.

In the past, we distinguished between Information Systems and Computer Science associate editors, but going forward we will be dropping this distinction due to the fuzzy boundary between the disciplines. The current editorial team is as follows:

Editor-in-Chief	Katherine Malan	University of South Africa
Assistant Editor	Ian Sanders	University of the Witwatersrand
Associate Editors	Marijke Coetzee	North-West University
	Sigrid Ewert	University of the Witwatersrand
	Aurona Gerber	University of the Western Cape
	Hugo Lotriet	University of South Africa
	Tendani Mawela	University of Pretoria
	Deshen Moodley	University of Cape Town
	Hanlie Smuts	University of Pretoria
	Terence van Zyl	University of Johannesburg
Production Editor	Etienne van der Poel	University of South Africa

I am very grateful to all current and past members of the editorial team. Your service is critical to ensuring that SACJ continues to run effectively.

Malan, K.M. (2024). Editorial: Winter 2024 Update [Editorial]. *South African Computer Journal* 36(1), vii–ix. https://doi.org/10.18489/sacj.v36i1.19291

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Submission statistics

For information, we present the following statistics around submissions, acceptance rates and the processing time of articles.

Year	**2022**	**2023**
Submissions	111	95
Desk rejection	54	61
Desk rejection rate	49%	64%
Final acceptance	17	12
Acceptance rate	15%	13%

The figures above translate into a rejection rate of approximately 86%. This may seem high, but it can be attributed to the large number of submissions from all over the world due to the indexing of SACJ on Scopus. In comparison, *South African Journal of Science*, which is also indexed on the Web of Science (Science Citation Index), reported a rejection rate of 95% in 2023.

In terms of submission processing time, the median time to a first decision (*desk reject / send to review*) is 4 days and the median time to final decision for submissions sent to review is 5 months.

Research in this issue

The research papers in this issue cover a range of topics from agility, programming proficiency, AI adoption and cybersecurity learning capability, to curriculum design for knowledge management.

- *A conceptual framework for agility in sociotechnical contexts* by Lillie, Eybers and Gerber.
- *Factors that influence computer programming proficiency in higher education: A case study of Information Technology students* by Ranjeeth and Padayachee.
- *Towards Human-AI Symbiosis: Designing an Artificial Intelligence Adoption Framework* by Smit, Eybers and van der Merwe. This is the second paper of a special issue of extended papers from the SAICSIT 2022 conference handled by guest editor, Prof Aurona Gerber.
- *Understanding the inertial forces impeding dynamic cybersecurity learning capabilities: The case of a South African healthcare software services firm* by Nyakasoka and Naidoo. This paper is the third and final paper in the special issue of extended papers from the SAICSIT 2022 conference.

- *Sensemaking and the Potential Future-focused Curriculum for Society 5.0 Knowledge Managers: A South African Perspective* by Mearns, Meyer, Holmner, Marshall, Hattingh and Bester. This paper was presented at the Knowledge Management South Africa Imbizo 2023, and the post-conference review process was handled by Prof Hanlie Smuts.

In addition to the research papers, we also have a letter to the editor from our colleagues at the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine providing an update on their recent research endeavours. We hope this letter creates awareness of the commendable work of this group on e-rehabilitation technologies for military personnel in war-torn Ukraine.

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Research Article

A conceptual framework for agility in sociotechnical contexts

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ABSTRACT
Organisational agility is crucial for organisations to thrive in dynamic business environments. While the Information Systems (IS) discipline recognises the need for IS to support organisational agility, current IS research has not sufficiently explained how organisations achieve agility given their sociotechnical contexts. Some scholars and practitioners propose scaling agility-building approaches from small software development teams to the enterprise level, and others argue that agility is not a predetermined outcome of linear processes, but instead emerges from intricate organisational contexts. Previous research proposed a conceptual model that identified the structural components of agility in IS. However, this structural perspective does not address the dynamic aspects of agility. To address this gap, two systematic literature reviews (SLR) were conducted to develop a conceptual framework for agility in sociotechnical contexts, which is the contribution this research makes to the IS field. The first SLR investigated frameworks that enable organisational agility. Consequently, the Cynefin framework was adopted to explain the dynamics of contextualised decision-making and agility. The second SLR identified the influence of heuristics on decision-making and dynamic capabilities. The resulting framework integrates the structural and dynamic aspects of agility in IS and explains how heuristics could potentially be managed to improve sociotechnical agility.

Keywords agility, sociotechnical, complex adaptive systems, dynamic capabilities, Cynefin, critical systems heuristics

Categories • **CCS ~ Social and professional topics, Professional topics, Management of computing and information systems**

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1 INTRODUCTION

Unpredictable disruption, hypercompetition, and turbulence result in uncertainty in the business environment, requiring enterprises to successfully manage such uncertainty, which is a key feature of organisational agility (Teece et al., 2016). Agility enables businesses to adapt swiftly to unpredictable internal and external changes in a highly dynamic environment by

Lillie, T. and Eybers, S. and Gerber, A (2024). A conceptual framework for agility in sociotechnical contexts. *South African Computer Journal* 36(1), 1–39. https://doi.org/10.18489/sacj.v36i1.18878

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effectively managing and adapting their operations and processes beyond normal levels of flexibility (van Oosterhout et al., 2006). However, achieving and maintaining agility is expensive, is not relevant to all organisational situations and can sometimes be counterproductive to the organisation's success (Teece et al., 2016; Walter, 2021).

Agile software development approaches aim to help small software development teams deliver increased business value faster in short prioritised iterations (Boehm & Turner, 2004). However, what it means to be "agile" in sociotechnical contexts remains elusive (Baham & Hirschheim, 2022). Sensing and responding capabilities are central themes for agility in strategy, management, and IS literature (Tallon et al., 2019). Decision-making capability and dynamic capabilities enable organisational agility by enabling managers in organisations to sense, decide and act in high-speed predictable and unpredictable contexts (Park et al., 2017; Pavlou & El Sawy, 2011; Teece et al., 2016). However, agility is an emergent phenomenon at the team level (Werder & Maedche, 2018), and problems arise in attempts to scale agility to the enterprise level (Limaj & Bernroider, 2022), as simply having more Agile teams does not produce organisational agility (Sidky, 2017). According to Denning (2016), large-scale Agile frameworks, such as the Scaled Agile Framework (SAFe), regularly fail because they attempt to "align" Agile teams with corporate goals relating to shareholder interests and achieving quarterly business targets. Instead, Agile practices should focus on delivering value to the business in short iterations. This divergence results in the ongoing tension between the enterprise and the Agile team levels in the organisation (Denning, 2016).

Previous research has identified the structural components of agility in IS (Lillie et al., 2023; Park et al., 2017). However, this structural perspective does not address the dynamic aspects of agility to explain how organisations can achieve agility in their IS. This presented a gap in scientific IS literature that this study aimed to address by developing a conceptual framework for agility in sociotechnical contexts. This study adopts the definition of a framework as a model (graphical representation and description of components and their relationships) and a method (goal-oriented activities and guidelines) for its implementation (Kotze et al., 2015; March & Smith, 1995). The method used to develop a conceptual framework for agility in sociotechnical contexts was to systematically review scientific literature for existing constructs that can explain the dynamics of, and the underlying influences on, agility in organisations.

The rest of this manuscript is structured as follows: Section 2 provides background about the agility problem in sociotechnical contexts. In order to explain the dynamic aspects of agility, an SLR of frameworks, including models and methods that enable agility in complex organisational contexts, was conducted in Section 3 to answer the first research question: What scientific frameworks, models or methods enable agility in complex organisational contexts? The results of this first SLR initiated the development of the conceptual framework for agility in sociotechnical contexts, and identified the Cynefin framework, grounded in complex adaptive systems theory, which could be used to explain the dynamics of contextualised decision-making and agility in complex and complicated organisational environments.

However, complex organisational situations challenge decision-making because uncertainty is constant and brings the risk that desired outcomes may not be achieved due to actor biases (Tversky & Kahneman, 1974). Additionally, the intricate interplay between human organisation and IS's technical aspects can lead to unintended and undesirable outcomes (Cecez-Kecmanovic et al., 2014). In situations of uncertainty – where problems are unclear, multiple solutions exist, and probabilities of outcomes are unknown – humans typically rely on heuristics to make decisions based on incomplete information (Gigerenzer & Gaissmaier, 2011). Acknowledging the role of heuristics in decision-making raised the second research question, which was addressed by the SLR in Section 4, concerning how to enhance the framework for agility in sociotechnical contexts: How do heuristics influence dynamic capabilities in organisational contexts?

In Section 5, the resulting framework is presented as the contribution of this study, a conceptual framework (a model and a method) for agility in sociotechnical contexts. This framework integrates the structural and dynamic aspects of agility, explaining how heuristics could potentially be managed to improve agility in sociotechnical contexts.

2 BACKGROUND

The organisational sense-response framework, proposed by Park et al. (2017), acknowledges that sense-respond capabilities are foundational to agility in IS, and support organisational agility (Sambamurthy et al., 2003; Tallon et al., 2019). The model of agility in IS proposed by Lillie et al. (2023) offers three categories for the characteristics of agility in IS:

1. sociotechnical contexts are complex and complicated,
2. dynamic capabilities operate at the managerial level to govern team and individual actions, and
3. agility features manifest in the actions of teams and individuals.

Even though these constructs imply organisational levels in an agility-generating sense-response process flow, they do not explain the dynamic aspects of agility and how the different components relate across the levels of organisational context, managerial capabilities and individual and teams' sociotechnical actions.

In IS research, systems involving technical and social components are considered complex, and Social Science involves "social systems" (Gregor, 2009). Thus, sociotechnical contexts should be considered from a systems perspective and take into account theories related to systems theory and complex systems theory to explain the dynamic processes of complex and complicated sociotechnical contexts. Meadows (2008, p. 205) defines a "system" as "*[a] set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviour.*" Systems theory in organisational science is an antecedent of dynamic capabilities theory and understands organisations as social systems comprising subunits that interrelate congruously and harmoniously, supporting the organisation's effectiveness (Teece, 2018).

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Complicated problems in organisations can be solved when the required expertise is available and utilised by applying rules and routines, and through command-and-control approaches that rely on embedded organisational processes and hierarchies (Nason, 2017). However, the daily realities of organisational life are complex as they are rife with multiplicity, contingency and emergence (Feldman & Orlikowski, 2011), and change is the prevailing organisational state (Tsoukas & Chia, 2002). Organisational change, such as an improved state of agility (Teece et al., 2016), can be achieved when managers use dynamic capabilities to govern the activities and actions of their teams (Teece, 2014).

Organisations that include social agents cannot be explained or described as aggregations of coexisting micro-situations, nor are macro-processes the aggregated product of interactions at the micro-level despite the profound implication of embodied behavioural patterns at the micro-level (Giddens, 1984). Agility is an emergent phenomenon (Werder & Maedche, 2018), and interactions at the micro-level allow collective constructs to change over time (Eisenhardt et al., 2010). In other words, nonlinear evolutionary processes and interactions at a micro-level emerge phenomena, such as agility, at a macro-level.

Meyer et al. (2005, p. 471) explain that "*[n]onlinear systems cannot be understood without conceptualizing and studying them at multiple levels. ...[o]rganizations are entangled in an ecology in which one agent's actions help construct another agent's environment, generating forces that connect social structures at different levels.*" Therefore, Meyer et al. (2005) encourage researchers to apply a complex adaptive systems (CAS) lens to organisational studies and advocate an approach to organisational research that takes a contextual, coevolutionary, processual, multi-level and emergent perspective. Therefore, this study identified a need to explain the dynamic components of agility in sociotechnical contexts both as a model and a method that provides a scientifically grounded conceptual framework that can be applied to and tested in real-world sociotechnical contexts to develop the framework's practicality further. Thus, this study aimed to develop practical explanations for the conceptual model's constructs so that these could potentially be applied to case study or action research in real-world contexts.

3 AGILITY IN COMPLEX AND COMPLICATED ORGANISATIONAL CONTEXTS

The structural components of agility in IS represented as a conceptual model of agility in IS developed by Lillie et al. (2023) is based on the organisational sense-response process loop by Park et al. (2017), and served as the starting point for this study. The conceptual model of agility in IS (Lillie et al., 2023) incorporates three organisational levels:

1. the sociotechnical context level, which is the organisational environment within which IS strategy and leadership steer the organisation towards achieving agile IS as a strategic objective;
2. the dynamic capabilities level, comprising managerial capabilities that govern the organisation's IS operations and initiatives/projects towards achieving agility; and

3. the team and individual action level where IS work practices can achieve agility in operational and project/initiative activities.

The conceptual model of agility in IS (Lillie et al., 2023) proposed that the agility features of competence, responsiveness, speed, reusability, flexibility, leanness, and scalability manifest in the actions of teams and individuals. This study adopted these seven agility features identified from the literature by Lillie et al. (2023), which are summarised in Table 1.

Table 1: Features associated with agility in IS (based on Lillie et al. (2023, pp. 158–159)

Feature	Association with agility in IS
Competence	Having the knowledge, skills, abilities, and technical capabilities that enable the organisation to adapt, innovate and seize opportunities in rapidly changing business environments, resulting in effective responses to change, thereby supporting strategic agility.
Responsiveness	Refers to proactive adaptation whereby an organisation can react positively to changes in its competitive and regulatory environment. Organisational agility is enhanced by its ability to sense and respond appropriately and timeously to opportunities and threats.
Speed	The rate of change whereby an organisation can proactively adapt, embrace change, and respond effectively to opportunities and threats in its internal and external environment. To achieve agility, speed should be appropriately pursued because a slower, more suitable response is sometimes better than a rushed, unsuitable response.
Reusability	Implies the strategic practice of leveraging existing IT capabilities to address new business challenges, fostering operational agility, and potentially reducing costs.
Flexibility	Implies the readiness and propensity of an organisation's IT capabilities to adapt to perpetual environmental changes, scale with demand, and align dynamically with business strategy, thereby enabling organisational agility.
Leanness	Refers to the strategic practice of contributing to value delivery through economy, quality, and simplicity. The cost of change should be considered, as agility often comes at the cost of efficiency.
Scalability	Having the sociotechnical capacity to adapt to an increased workload while benefiting from economies of scale, thus supporting agility by enabling growth while limiting constraints on resources. Scalability can be achieved at any level in an organisation, and is enhanced when avoiding functional siloes, and standardising IT practices for cross-functional use.

The model of agility in IS proposed by Lillie et al. (2023) does not address the dynamic aspects of agility, that is, how these can be enabled. An SLR was conducted to answer the first research question:

What scientific frameworks, models, or methods enable agility in complex organisational contexts?

3.1 Method: a systematic literature review of frameworks for enabling agility in complex organisational contexts

The systematic literature search and review of frameworks, models, methods and strategies that enable agility in complex organisational contexts was directly shaped by the keywords "framework", "model", method", or "strategy" (to find implementable constructs), "sense" and "respond" (implies agile capabilities in organisations), and "complexity", "uncertainty" or "unpredictability" (all relate to complex organisational contexts). Scopus was selected as the research database for its advanced search options and inclusion of mainly peer-reviewed literature from top-rated IS journals.

The following search expression was applied to title, abstract and keyword fields, and it limited the results to journal articles in English from the Social, Computer, and Business Sciences:

```
TITLE-ABS-KEY (
  (("sense-respond" OR "sense and respond" OR ("sense" AND "respond"))
   AND
   ("strategy" OR "framework" OR "model" OR "method")
   AND
   ("complex" OR "complexity" OR "uncertainty" OR "unpredictability")))
  AND (LIMIT-TO (SRCTYPE, "j"))
  AND (LIMIT-TO (SUBJAREA, "SOCI")
      OR LIMIT-TO (SUBJAREA, "COMP")
      OR LIMIT-TO (SUBJAREA, "BUSI"))
  AND (LIMIT-TO (LANGUAGE, "English")
)
```

This search returned 175 articles from which works on computational models/frameworks/ methods/strategies for sensing and responding, technological frameworks, and articles not relevant to organisational sensing and responding in complex organisational contexts were excluded. Highly cited, seminal, peer-reviewed articles from prominent authors were included in the final set of 13 articles, which were then analysed to answer the research question. The SLR process was based on the guidelines proposed by Okoli (2015) and is presented in Figure 1.

3.2 Analysis and findings

Using Webster and Watson's (2002) concept-centric approach, the articles found through the SLR process were summarised based on the concepts' relevance to how agility can be enabled in complex organisational contexts, considering:

1. the construct's objectives or goals,
2. the construct's theoretical foundations,
3. the construct's applicable contexts (what "complexity" means to the construct),

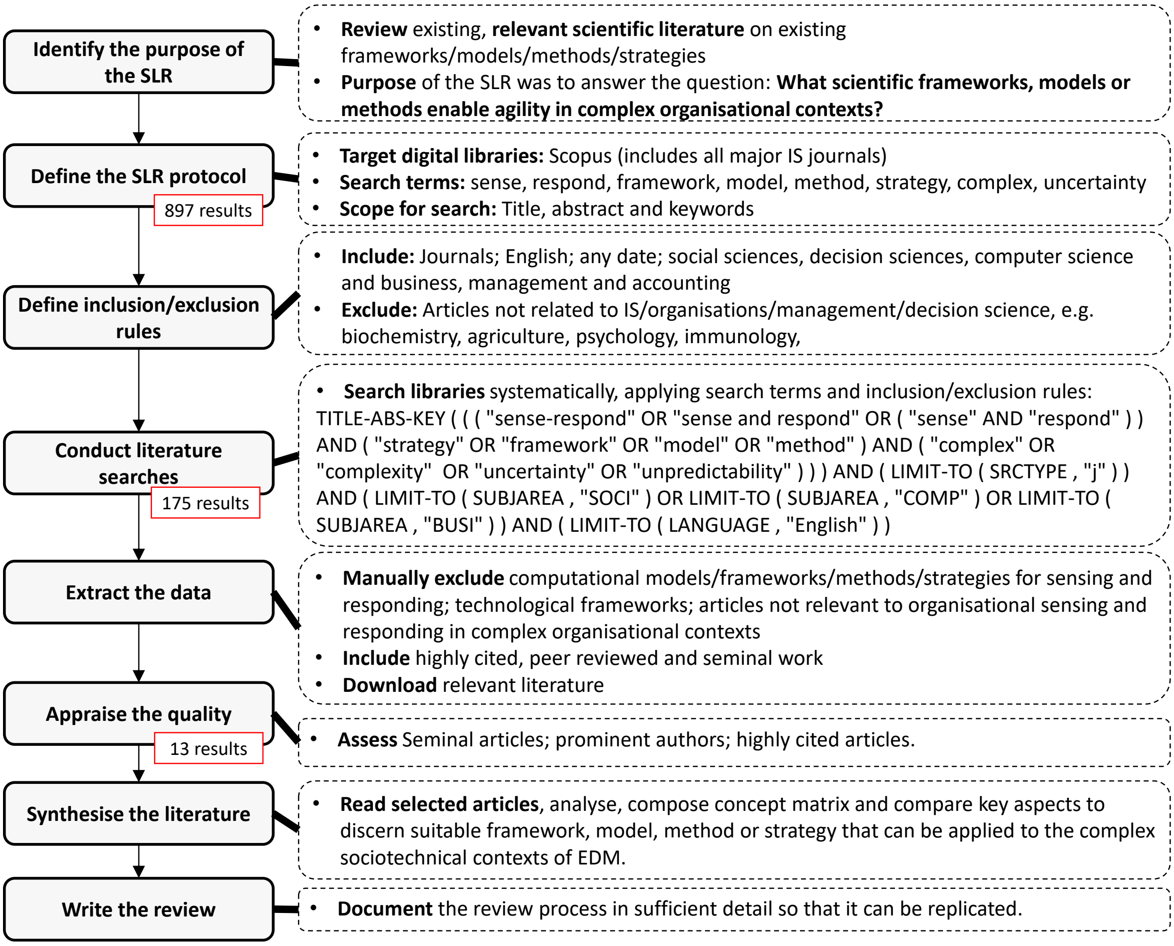

Figure 1: Systematic literature review process to find existing frameworks, models, methods and strategies for enabling organisational agility (based on Okoli (2015, pp. 883–884))

4. the construct's components (descriptions of components, relationships and processes), and
5. the construct's scope of application within organisational contexts.

Table 2 presents a summary of the findings in a concept matrix. The most relevant points were selected from each article and are highlighted in Table 2 using a coloured background to emphasise pertinence to the components of the conceptual model of agility in IS proposed by Lillie et al. (2023): complex and complicated sociotechnical contexts, dynamic capabilities (sensing, learning, coordinating and integrating), and agility features in IS. The various types of constructs found were framework (F), model (M), strategy (S) and tool (T), as indicated in the first column.

Table 2: Frameworks, models, methods and strategies for enabling agility in complex organisational contexts

Type	Construct objectives	Theoretical foundations	Contexts to which the construct applies	Construct components	Scope of application for the construct
Ramnath and Landsbergen (2005)					
S	Enable unified IT and organisation sense and respond strategy.	Evolutionary theory of economic change; Public Administration Theory	Change, uncertain demand, and reduced budgets	Strategic plan and execution process	IT and city government departments, taking a "fractal" view of "organisations-within-organisations"
Mathiassen and Vainio (2007)					
F	Approach to understanding dynamic capabilities in small software firms; proposes principles for managers to apply the framework.	Dynamic capabilities	Highly complex and turbulent	Capabilities and principles for sense-and-respond	Small software firms
Snowden and Boone (2007)					
F	Enable leaders at any organisational level to sense and decide on appropriate action in a prevailing operative context.	Complex systems	Complex, complicated, clear & chaotic	Describes dynamics between complex, complicated, clear and chaotic domains with awareness of the context	Contextualised application to any organisation/ part of an organisation
Collins et al. (2010)					
F	Enable a deeper understanding of relationships between knowledge management capabilities, supply chain technology investments, and overall firm performance enabling managers to adapt to changing environments effectively.	Not specified	Supply chain complexity	Resources, keys to effective utilisation, operational result, strategic result; output measures	Firms with complex supply chains
Strachan (2011)					
S	Question strategy as being underpinned by an actionable plan providing long-term predictability. Avoid conflating strategy with grand-strategy.	Theories of strategy and contingency	Uncertainty	Infinite flexibility; embrace contingency and long-term interests; strategy requires context and awareness of the effect on stakeholders	Military and national security contexts
Thiel et al. (2012)					
M	A sensemaking model that enables leaders to make ethical decisions.	Sensemaking	Complex and high-stakes situations	Sensemaking strategies based on personal, situational, and environmental constraints	Leadership in organisations
Liu (2013)					
M	Enable sustainable competitive advantage by integrating manufacturing strategy, transformational leadership, and technology.	Resource based view of the firm	Dynamic, complex, and turbulent business environments	Manufacturing strategy, technology strategy, dynamic decisions, sense & respond, transformational leadership	Manufacturing operations

[continued ...]

Table 2: [... continued]

Type	Construct objectives	Theoretical foundations	Contexts to which the construct applies	Construct components	Scope of application for the construct
Brookfield (2018)					
F	Enable risk mitigation through adaptation of the organisation from the interactions between accounting technologies and risk as an environmental factor.	Theory of the firm	Uncertainty as a general representation of risk; complexity	Nature of the firm, accounting as risk management IT, transaction cost economics	Financial risk management in organisations
Tilabi et al. (2019)					
T	Enable decision-making and strategy-making about firms' technologies for product and process development.	Miles and Snow Typology; Resource based view of the firm; Competitive advantage	Uncertainty and turbulence	Prospector, analyser, defender, and reactor. Responsiveness, agility, leanness, and flexibility. Quality, time, and cost.	High-tech startup organisations in large mass-production industries
Øvrelid and Sanner (2020)					
M	Lightweight IT extends digital infrastructure and enables organisations to sense and respond continuously to the effects of process innovation.	Dynamic complexity in information infrastructures	Complex organisational settings	Sense-able process innovation to digitalise, visualise, manage, and re-evaluate information infrastructures	General hospital as a complex organisational setting
Lane et al. (2021)					
F	Enable pragmatic leadership with a sense-making framework to "act-probe-sense-respond" in time-critical crisis situations.	Complex systems	Volatility, uncertainty, chaos, and ambiguity (VUCA)	Describes act-probe-sense-respond actions in chaotic healthcare contexts	Complex and time-critical medical emergency scenarios
Heino and Kalalahti (2021)					
F	Enable understanding of experts' decision-making in critical situations, considering the potentially detrimental effects of relying on pre-established procedures.	Naturalistic decision making; Cognitive task analysis	Complexity, uncertainty, and ambiguity	Notice unusual circumstances, identify the bigger picture, make decisions, improvise to overcome obstacles, start immediate action	Expert professional first responders in unexpected situations
Mero and Haapio (2022)					
M	Enables effectual decision-making in executing dynamic capabilities under unexpected uncertainty.	Effectuation; Dynamic capabilities	Unexpected uncertainty	Describes activities for reconfiguration of organisational capabilities and processes	Business-to-business firms

The construct objectives of five of the articles were found to be relevant to the characteristics of agility in IS, as proposed by Lillie et al. (2023). The other eight articles proposed constructs applicable to a narrow scope of organisational situations such as small software firms, supply chain technology investments, ethical decision-making, and manufacturing strategy. The Cynefin framework proposed by Snowden and Boone (2007) is underpinned by complexity theory and systems thinking, and enables leaders at any level in the organisation to sense the nature of the ongoing context and decide on an appropriate course of action.

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Theoretical foundations: The theoretical foundations of the construct in five of the found studies are relevant to agility in IS as they incorporate dynamic capabilities or organisational complexity, which are structural components of agile IS (Lillie et al., 2023).

Contexts for construct application: In some of the reviewed articles, the context to which the construct was applied was narrowed down to a specific scope, thus less generalisable, such as reduced budgets (Ramnath & Landsbergen, 2005), supply chain complexity (Collins et al., 2010) and unexpected uncertainty (Mero & Haapio, 2022). The framework proposed by Snowden and Boone (2007) differentiates between complex, complicated, clear and chaotic domains within which leaders at all levels of an organisation must make sense of the operative contexts to decide and respond appropriately.

Construct components: Most of the constructs reviewed provided descriptive representations, including strategic plans and process steps (Ramnath & Landsbergen, 2005), capabilities and principles (Mathiassen & Vainio, 2007), required resources and measurable results (Collins et al., 2010), sensemaking strategies based on constraints (Thiel et al., 2012), and activities for the reconfiguration of organisational capabilities and processes (Mero & Haapio, 2022). Snowden and Boone's (2007) Cynefin framework specifically described the dynamics of navigating the complex, complicated, chaotic and clear domains of organisational contexts for effective decisions and responses.

Scope of application of the construct: The constructs proposed by the authors were, in most cases, applicable to a specific organisational context, for example, military and national security contexts (Strachan, 2011), high-tech startup organisations in large mass-production industries (Tilabi et al., 2019), business-to-business firms (Mero & Haapio, 2022), and firms with complex supply chains (Collins et al., 2010). Ramnath and Landsbergen (2005) provide an interesting "fractal" perspective of "organisations-within-organisations". The Cynefin framework proposed by Snowden and Boone (2007) offers a broad scope for contextualised application of their framework to any type of organisation or any part of an organisation.

3.3 The Cynefin framework applied to agility in sociotechnical contexts

The Cynefin framework proposed by Snowden and Boone (2007) offered the most relevant and generalisable explanation for the dynamics of sensing and responding, which are the key capabilities of organisational agility, in complex and complicated organisational contexts. Cynefin is a decision support framework that enables organisations to sense and respond effectively in complex, complicated, clear and chaotic contexts (Kurtz & Snowden, 2003; Snowden, 2021b; Snowden & Boone, 2007; Snowden & Rancati, 2021). Cynefin describes three primary types of systems: Ordered, Complex and Chaotic/un-ordered. An ordered system describes the clear and complicated domains (Snowden & Rancati, 2021). In a system where all events have an equal probability of occurring, all events are random, and nothing can emerge from its chaotic state (Juarrero, 2015a). Emergence is also irrelevant when a system is in perfect equilibrium where all events are perfectly predictable, and nothing can emerge from its clarity (Juarrero, 2015a). When actors in an organisational context are cognisant of the nature of the ongoing situation in terms of the domains proposed by the Cynefin framework, they can critically assess when and how to appropriately adopt or adapt methods and approaches for favourable outcomes (Snowden & Rancati, 2021). Figure 2 maps the components of the conceptual model of agility in IS (Lillie et al., 2023) onto the complex and complicated domains of Cynefin (Kurtz & Snowden, 2003; Snowden & Rancati, 2021).

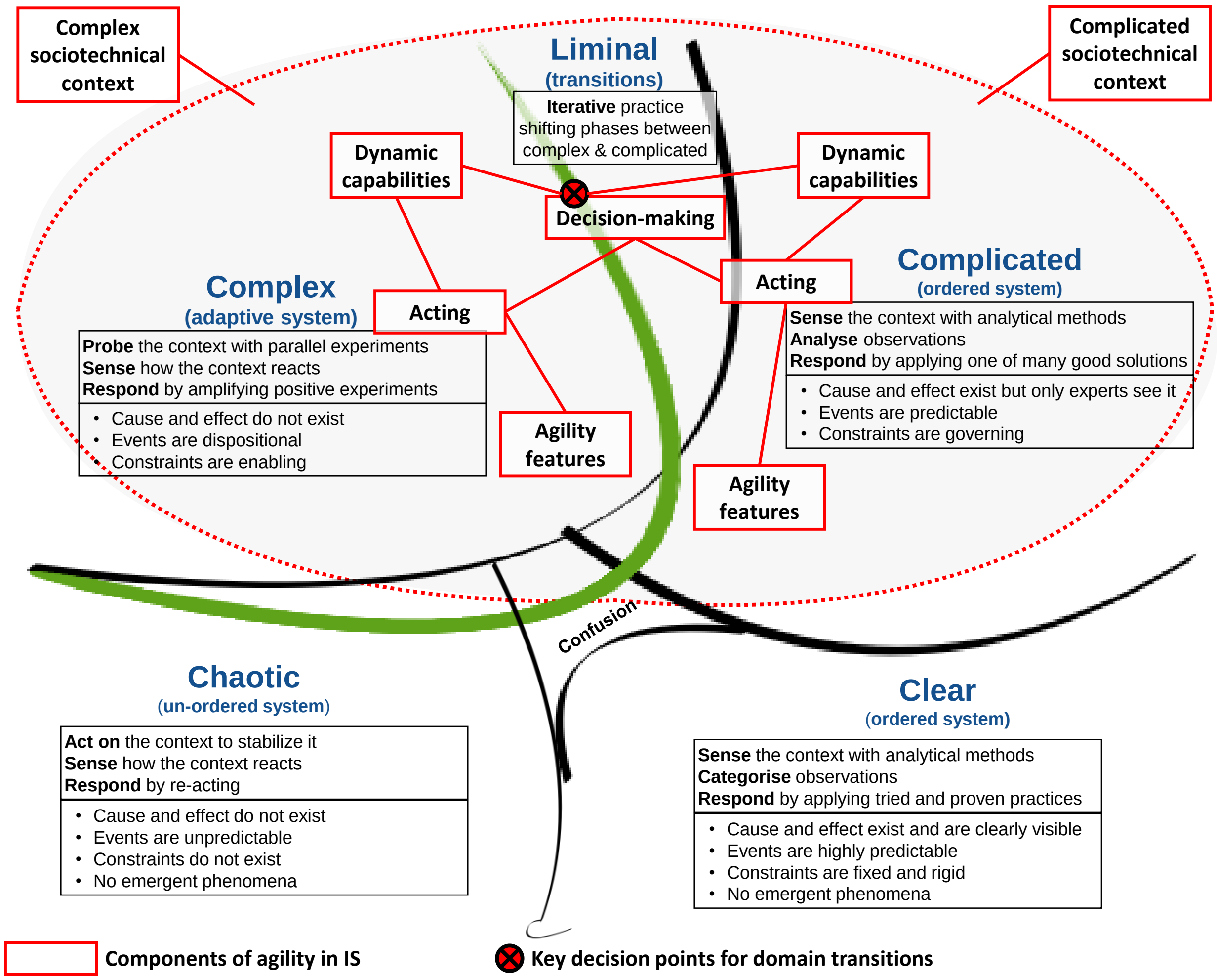

Figure 2: The components of agility in IS mapped to the Cynefin framework (based on Juarrero (2000); Kurtz and Snowden (2003, pp. 464–466); Lillie et al. (2023); Snowden and Rancati (2021, pp. 60–63)).

Complex and complicated organisational contexts: Systems involving human agents are invariably complex, comprising many interacting agents with multiple identities depending on their role in the unfolding context (Snowden, 2002). Kurtz and Snowden (2003) define complicated contexts as the domain of "known unknowns" where experts can solve problems. In contrast, they define complex contexts as the domain of "unknown unknowns", where uncertainty hinders expert approaches to solutions. Under conditions of certainty in organisations, the whole comprises the sum of the parts. However, in complexity, the whole is irreducible and transcends the sum of its parts (Simon, 1996). Thus, in the domain of order, the whole can be optimised by optimising the parts, and problems are solved using reductionist approaches (Kurtz & Snowden, 2003). In the complex domain, the sum of the parts can never add up to the whole because all attempts at characterisation, identification or intervention modify the system itself (Kurtz & Snowden, 2003; Simon, 1996). Therefore, suboptimal performance in complex contexts must be allowed for each component to optimise the whole, as problems can only be resolved through emergence (Kurtz & Snowden, 2003).

Decision-making and transitions between complex and complicated organisational contexts: Cynefin offers explanations for the dynamics of transitioning between the complex, complicated and clear domains through key decision points at the liminal boundaries between complex and complicated contexts. Stable patterns emerging from the continuous iterations between the complex and complicated domains can evolve sufficiently to be routinised for longer-term embedment in best practice, thus moving into the clear domain (Snowden, 2021b; Snowden & Rancati, 2021). Some patterns cannot be stabilised, resulting in continuous iteration between complex and complicated, for which the flow must be constantly navigated to keep the system moving towards a favourable state (Juarrero, 2000; Kurtz & Snowden, 2003; Snowden, 2021b; Snowden & Boone, 2007). The complex domain requires pattern management, and the patterns are the phenomena that emerge from the interactions of the agents in the system (Snowden, 2002). Cynefin defines a liminal area at the boundaries of its different domains, and transitioning from the complex to the complicated domain occurs when actors are still uncertain but stabilising patterns are emerging (Snowden & Rancati, 2021).

Transitioning from complicated to complex occurs when expert solutions (or "good practice") are called into question and are not providing the desired outcomes (Snowden & Rancati, 2021). Turner et al. (2022) emphasise that it is crucial to discern the need to apply different methods as the context transitions from one domain to another. Effective decisions can be made by assigning the situation to the appropriate Cynefin domain, enabling contextually appropriate interventions (Snowden & Boone, 2007). Snowden (2002), Kurtz and Snowden (2003), and Snowden and Rancati (2021) specifically include CAS theory, authored by Holland (1992), to underpin Cynefin for explaining the nature and dynamics of complex and complicated decision-making environments. Therefore, adopting Cynefin to explain the dynamics of agility in sociotechnical contexts naturally requires adopting CAS theory.

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3.4 Discussion: sociotechnical contexts as complex adaptive systems

When applying CAS models to strategic management, an approach unfolds whereby systems can be built to swiftly evolve effective adaptive solutions in a dynamic environment (Anderson, 1999). The Cynefin framework incorporates CAS as the theoretical foundation for the complex domain, and Systems Thinking guides understanding and navigation of the complicated domain (Kurtz & Snowden, 2003; Snowden, 2015; Snowden & Rancati, 2021). A CAS is a complex system that is an open dynamic system, continually reconfiguring its structure through self-organisation, requiring the exchange of energy and information (Juarrero, 1999; Snowden & Rancati, 2021; Turner & Baker, 2019).

Holland (2014, p. 24) explains that "*[CASs] are composed of elements, called agents, that learn or adapt in response to interactions with other agents.*" CAS theory provides a lens through which to perceive systems of interacting agents and how order emerges from the interactions in dynamic organisational environments that require responsiveness and adaptation, such as IS (Onik et al., 2017). "*[CASs] are understood from the bottom up, built from interactions of the individual elements*" (Teece, 2018, p. 362). A system is a CAS when it adapts to and evolves with changes in its environment (Holland, 2006), coevolving and continuously self-adapting towards a state of optimised fitness, producing stability and sustainability without being centrally controlled (Anderson, 1999). In socially complex systems, human agents can create their own "adjacent possibilities" and, through creativity stemming from their sentient nature, can consciously influence the dynamics of the complex system (Beckage et al., 2013). The remainder of this section synthesises the literature on mechanisms underlying a CAS's dynamics.

Constraints: Enabling constraints in a CAS are context-sensitive, operating bottom-up (or part-to-whole), supporting the emergence of phenomena and, on closure, expanding the probability space of the system (Juarrero, 2015b). In contrast, governing constraints in a CAS are restrictive and function top-down (or whole-to-part), incorporating isolated and independent components into a coherent unit, thus maintaining, regenerating and evolving the whole system (Juarrero, 2015b). Governing constraints act as rules that iteratively evolve emergent novelty towards adoption and embedment as good practice in the complicated domain (Snowden & Rancati, 2021). In contrast, enabling constraints are context-sensitive and flexible, adapting to the changing context (Snowden & Rancati, 2021), and allowing new phenomena and system states to emerge (Juarrero, 2000). Governing constraints are context-free, existing independently of the context of the system, and restrictive in that they increase the probabilities of certain events occurring as they are always consistently applied, for example, shared goals, purposes and understanding (Juarrero, 2015a). Governing constraints restrict the emergence of novelty, such as emerging new approaches to teamwork (Snowden & Rancati, 2021), because agents continue to operate under the same rules, creating interdependencies between the components (Juarrero, 2015b). However, transpiring interrelationships between the components in a complex dynamic system create a foundation for emergence in the system (Juarrero, 2015a). The recursive process of constraints stemming from intention and capacity, acting top-down from the global level of the CAS, keeps the system operating close to the boundary between complicated (more control) and complex (less control) (Cilliers, 1998; Juarrero, 2000; Kurtz & Snowden, 2003).

Feedback loops: Feedback loops in a CAS are dynamic mechanisms that offer opportunities to transition the system state between the complex and complicated domains (Snowden & Rancati, 2021). Heeding feedback loops in a CAS can shift the system state from the complex to the complicated domain as previous unknowns become knowable through improved experience and expertise gained within the current timeframe and context (Snowden & Rancati, 2021). Short iterative cycles of work execution increase the frequency of interaction among agents in a CAS, supporting a better understanding of stakeholder requirements and thus enhancing the integration of new knowledge in the process (Werder & Maedche, 2018). When seeking endurance and stability, cadence is more important than velocity (Snowden & Rancati, 2021).

Juarrero (2000, p. 26) explains that "*[CAS]s are typically characterized by positive feedback processes in which the product of the process is necessary for the process itself.*" Feedback and catalysts in a CAS influence how the components in a CAS interconnect and combine, providing the system with enabling constraints, and changing the probability landscape of future events (Juarrero, 2015b). Negative feedback suppresses large perturbations in a CAS, causing the system to stabilise, whereas positive feedback drives autocatalysis, amplifying even small fluctuations, thus moving the system far from equilibrium (Heylighen et al., 2007). Positive feedback allows for transformation in social systems when governing constraints can no longer exterminate or suffocate deviations, thus allowing them to amplify, leading to future transformations (Morin, 2007). Thus, feedback changes the probability landscape for subsequent transformations, shaping how change happens in a CAS (Juarrero, 2015b).

Transitions: During a transition in a CAS, the constraints operating in the preceding system state undergo a qualitative reconfiguration, renewing relationships among the system's internal components and between the system and its environment (Juarrero, 2000). When a CAS transitions between complexity and complicatedness, it is crucial for the organisation's survival to use the opportunity to switch management approaches in concert with the changes in the system (Snowden & Boone, 2007). The liminal area between complicated and complex contexts has a transitionary and iterative nature, where good practice can be established in the complicated domain through a transitionary process requiring energy to shift and adopt new emergent practices from the complex domain (Snowden & Rancati, 2021). By intentionally understanding the system's environment and changing attributes within its context, transition to a more manageable domain, for example, shifting from complex to complicated, is achievable (Turner et al., 2022).

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Emergence and evolution: Agility is an organisational phenomenon that emerges from complexity and evolves in complicatedness (Crick & Chew, 2020; Werder & Maedche, 2018). In complex contexts, multiple agents interact in nonlinear ways, and emergence occurs from the dynamics of these interactions (Snowden & Boone, 2007). Viewing an organisation as a CAS provides explanations for how organisational capabilities and routines emerge and evolve from self-organisation in teams (Werder & Maedche, 2018) and through organisational learning processes (Bleda, 2017).According to Crick and Chew (2020), sociotechnical organisational routines are repeatable patterns of interaction that apply existing organisational capabilities to execute business processes that evolve and embed in practice, intending to align with managerial goals. Complexity literature describes "emergence" as various phenomena in CAS whereby the system transforms into a new state by learning to adapt to its changing environment (Turner & Baker, 2019). The notion of "emergence" stems from the system's nonlinear, rich and dynamic interactions, implying that the system's behaviour cannot be predicted by inspecting its individual parts (Cilliers, 2000), and the system's behaviour, as a whole, amounts to more than a simple aggregation of its parts (Holland, 2002). Emergence cannot be deduced from the qualities of its parts because it emerges from the complex system and its organisation as a whole (Morin, 2007). Juarrero (2000, p. 33) offers a summary of the emergence and evolution processes in a CAS: "*[CAS] exhibit true self-cause: parts interact to produce novel, emergent wholes; in turn, these distributed wholes as wholes regulate and constrain the parts that make them up.*"

Without constraints that govern and enable the system, there cannot be the emergence or evolution of phenomena in a CAS (Juarrero, 2015b; Snowden & Rancati, 2021). In a continual iterative process, enabling constraints allow the system to adapt and, at closure, emerge governing constraints that evolve the system through the embedment of knowledge, rituals and practices (Juarrero, 2015a, 2015b; Snowden & Rancati, 2021). As Juarrero (2015b) explains, the repeating dynamic iterations of constraint closure stabilise configurations in the system, enabling self-direction and autonomy of the system's conscious, sentient and self-aware agents. With each iteration, newly emergent phenomena at the lower levels issue control and behavioural patterns that are then embodied at the global level of the CAS (Juarrero, 2015b, p. 520).

Hierarchy is a fundamental theme in complex systems architecture, meaning that any complex system is organised into multiple levels (Simon, 1962). CASs in organisations present fractal, thus multi-level, architectures that cannot be meaningfully investigated from a single-level perspective as this would contradict the fractal nature of complexity (Cilliers, 2001; Juarrero, 2015b; Ramos-Villagrasa et al., 2018; Salthe, 2012; Snowden & Rancati, 2021). A system is fractal when it has self-similarity across multiple levels. Self-similarity implies resemblance, as opposed to one-to-one equivalence, and similar but different variables operating at different levels can emerge and evolve changes bottom-up to higher levels in the system (Ramos-Villagrasa et al., 2018).

Salthe (2012, p. 351) proposes that a three-level hierarchy is suitable for modelling stability because "*a third level always anchors relations between the other two, and so the middle, focal level cannot be reduced either upward or downward by assimilation into a contiguous level.*" Crick and Chew's (2020) research on the microfoundations of agility in organisations applied Coleman's (1986) work on how individual action at the micro-level stimulates the emergence of phenomena at an organisation's macro-level. Similarly, Eisenhardt et al. (2010) applied Coleman's concept of individual actions influencing macrosocial functioning, proposing that organisational processes with shared heuristics emerge from the group and individual actions to improve firm performance. Sections 3.5 to 3.7 describe the three levels (macro-, meso-, and micro-level) of agility in sociotechnical contexts.

3.5 Macro-level: complex and complicated sociotechnical contexts

When organisational contexts are complex, organisational strategising, management routines, and planning can set a goal-based direction towards, but not control and guarantee, desired outcomes (Kurtz & Snowden, 2003; Park et al., 2017). When contexts are less complex and more complicated, and enough knowledge exists, experts can know how to predict and achieve desired outcomes (Kurtz & Snowden, 2003; Park et al., 2017). Thus, decision-making in complex and complicated contexts can have intended outcomes or unintended consequences for agility. Governing constraints at the overall level of a CAS constrains the system top-down, thereby maintaining and enhancing the system's state as a whole (Juarrero, 1999). Therefore, the overall sociotechnical contexts and strategic management at the macro-level exercise top-down constraints (whole-to-part) on the sociotechnical CAS as a whole.

3.6 Meso-level: dynamic capabilities in complex and complicated sociotechnical contexts

Teece (2023, p. 125) defines dynamic capabilities as "*a framework that recognizes complex interactions within a firm, with other firms, and with the business environment in a quest to understand long-run enterprise performance.*" Lillie et al. (2023) identified dynamic capabilities (sensing, learning, coordinating, and integrating) from the literature as characteristics of agility in IS. The original dynamic capabilities theory was authored by Teece et al. (1997), but was further explained for practical use in firm performance by Pavlou and El Sawy (2011). In an organisation, dynamic capabilities reside at the managerial level, where principles can be applied to trade-off agility for efficiency and represent higher-order capabilities that govern activities (Teece et al., 2016). For example, coordination capabilities are required to perform project management activities (Zheng et al., 2011), learning capabilities are needed to grow expertise and competence (Sambamurthy et al., 2003; Snowden & Rancati, 2021), a sensing capability is essential to make effective management decisions (Kurtz & Snowden, 2003; Teece, 2023), and integration capabilities are required to integrate deliverables into value-creating processes (Pavlou & El Sawy, 2011; Sambamurthy et al., 2003).

Entrepreneurial managers use dynamic capabilities to drive organisational change (Teece, 2014). Nijssen and Paauwe (2012, p. 3316) define the focus of dynamic capabilities as "*the process of transformation of organizations – as a result from changes in the environment – which leads to a break in routines and involves a shift in competencies and required knowledge.*" Eisenhardt et al. (2010, p. 1263) define the microfoundations of dynamic capabilities as: "*the underlying individual-level and group-level actions that shape strategy, organization, and, more broadly, dynamic capabilities, and lead to the emergence of superior organization-level performance.*" Therefore, dynamic capabilities are understood in this study to exercise top-down and bottom-up constraints (whole-to-part and part-to-whole) in complex and complicated sociotechnical contexts. The meso-level represents the sensing and seizing of opportunities for, and threats to, improving agility in complex and complicated sociotechnical contexts.

The options open to an organisation's paths through time are a function of its current position, shaped by its historical course and the possible trajectories towards a future state (Snowden, 2002; Teece et al., 1997). Dynamic capabilities are grounded in high-performance routines or patterns enacted within the organisation, shaped by the firm's history, and embedded in its processes (Teece & Pisano, 1994). The structural patterns of dynamic capabilities in an organisation vary depending on the level of volatility in the organisational environment. High-velocity environments exhibit semi-structured routinisation, whereas robust, structured patterns manifest in moderately dynamic organisational environments (Eisenhardt & Martin, 2000). Pavlou and El Sawy (2011) propose that the dynamic capabilities of sensing, learning, integrating and coordinating enable the creation and evolution of operational capabilities, reconfiguring them in response to changes in the environment.

Sensing in complex and complicated contexts: Turner et al. (2022, p. 1) define sense-making as the process of how "*we make sense of the world so we can act in it.*" Anticipatory awareness is a concept that is central to sense-making whereby complexity is approached by acknowledging that the future is unpredictable, thus considering what can be done in the present for a better future (Snowden, 2021a). In this study, the dynamic capability of "sensing" is enacted through sense-making. Understanding the present well enough to manage its evolutionary potential is crucial, thus navigating towards a favourable future state (Snowden, 2021a). Anticipatory schemata organise perception as the human agent anticipates new information as it is received and simultaneously integrates it with preexisting information (Giddens, 1984). According to Snowden (2021a), the message is to "do the next right thing", then scan the environment and repeat this process, thereby creating points to "stop and think" instead of formulating a plan upfront and expecting to execute it precisely from start to finish.

Learning in complex and complicated contexts: An organisation's capabilities are knowledge assets that must be gradually built up over time through organisational learning (Bleda, 2017). Transitioning the CAS from complex to complicated is an iterative learning process requiring energy to embed increased expert knowledge into practice (Snowden & Rancati, 2021). Feedback loops, adaptation, and evolution all pertain to a CAS's ability to learn (Turner & Baker, 2019). Learning is a process requiring time and space to allow

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for the emergence of new meaning (Snowden, 2002). Snowden (2002, p. 102) emphasises three changes required to the mindset for managing knowledge:

1. knowledge cannot be conscripted but only volunteered as it is impossible to tell whether someone is applying their knowledge, but their compliance to a process is assessable;
2. telling what we know requires less time than writing about it, and writing is a reflective process and cannot contain the exact and complete original thought or whole experience; and
3. "we only know what we know when we need to know it" – the context of someone's "knowing" must be recreated before one can ask meaningful questions about their knowledge or enable the use of their knowledge.

Thus, meaningful knowledge is contextual and requires interaction in its application in the real world (Juarrero, 2000).

Integrating in complex and complicated contexts: Giddens (1984, p. 28) defines integration in social systems as "*involving reciprocity of practices (of autonomy and dependence) between actors or collectivities*", thus complementing the distinction between reflective self-regulation and stable causal loops driven by an overall motivation to integrate routine practices in a CAS over space and time (Giddens, 1984, pp. 28, 64). Integration by mutual agreement of individual agents' efforts enables the team's effort to transcend the individual (Bolman & Deal, 2017). As Bolman and Deal (2017, p. 44) analogically explain, "*[a]ll rowers have to optimize their strokes for the benefit of the boat* ." Complexity studies revealed notable theoretical dynamics of emergence whereby unconnected and local forms of interaction evolve into interconnected forms, creating more institutionalised and integrated structures (Langley et al., 2013). However, the more complex an organisation's role structures become, where many people perform numerous diverse activities, the harder it becomes to sustain a tightly integrated, focussed organisation (Bolman & Deal, 2017).

Coordinating in complex and complicated contexts: Cooperation and coordination among diverse individuals are crucial for team performance because these enable synergy and synchronised motion, integrating individual efforts and transcending the individual (Bolman & Deal, 2017). Teams within a CAS are self-organising entities that adapt effectively by coordinating explicitly, such as sharing information and expertise within the team (Ramos-Villagrasa et al., 2018). The effectiveness of agents' coordination efforts across organisational boundaries depends on their skills and credibility in interacting with stakeholders (Bolman & Deal, 2017). By building informal networks that span across organisational silos, organisational teams' resilience when operating in complex contexts is enormously enhanced based on high levels of trust when working together (Snowden, 2002; Snowden & Rancati, 2021). Informal networks are context-specific entanglements that create very effective channels for information flow and coordination within the context of a specific need (Snowden, 2021a).

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3.7 Micro-level: teams and individuals acting in complex and complicated sociotechnical contexts

The cognitive processes of rationalisation, motivation and reflection underlie all human action and relate directly to human intention (Giddens, 1984). Processes of structuration in organisations generate routines from agents' actions that construct progressively coherent patterns of interaction, shared governance, collective awareness and information sharing (Meyer et al., 2005). However, technology affordances are not always predictable and controllable, making contexts where social and technological agents are entangled, brittle and ephemeral, resulting in intended and unintended consequences of agents' actions (Orlikowski, 2007). Meyer et al. (2005) explain that, in the entangled ecology of organisations, one agent's actions contribute to the construction of another agent's context, catalysing forces that form networks of social structures across different levels.

The individuals in organisational contexts act with awareness, purpose, and reflexivity, routinely and continually monitoring the flow of their own and others' actions as well as their enactments' physical and social contexts (Giddens, 1984; Orlikowski, 2002). Orlikowski (2002) views social agents, in addition to being reflexive, as knowledgeable and able to provide a rational account of their actions. Agents use opportunities and motivation to modify their practices by learning through reflection, improvisation and experimentation, whereby their "knowing" changes in concert with their practices (Orlikowski, 2002). However, Giddens (1984) points out that most agents' knowledge is practical, not theoretical, further distinguishing discursive knowledge as verbalisable from practical knowledge, which is tacit by nature. Therefore, the relationship between what agents know and how they apply what they know in their actions is not always discernible.

At the micro-level, agents' motivation, skills and interpretation of the organisational routines are enacted in their practices. Nevertheless, routines are subject to the agents' interpretation and are, therefore, subject to adaptation and workarounds as the agents sense and respond to constraints in the operative context (Crick & Chew, 2020). Actions at the micro-level contribute to collective organisational change over time (Eisenhardt et al., 2010) and emerge collective action at the macro-level (Meyer et al., 2005). Thus, actions and interactions at the micro-level exercise bottom-up constraints (part-to-whole). However, Giddens (1984) explains that, despite the significant influence of micro-level behavioural patterns on the overall system, it is not meaningful to understand the macro-processes of social organisations as aggregations of coexisting micro-situations or as aggregated products of interactions occurring at the micro-level.

3.8 Transitions: decision-making and heuristics in sociotechnical contexts

Lapalme et al. (2016) suggest that coordinated decision-making and acting are essential to cope with complexity and uncertainty. If agents acting in a system were perfectly rational and possessed complete knowledge to inform their choices at all times, they would be fully adaptable, fast and intelligent in taking the most beneficial action to achieve an optimal outcome

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for all situations (Waldrop, 1992). By allowing decisions to be made at the organisational level where understanding of the ongoing context is highest, and instilling a sense in the actors that they are part of a larger context, individuals and teams are empowered and enabled to cope with complexity (Lapalme et al., 2016). Nijssen and Paauwe (2012) emphasise that because dynamic environments are fast-paced, it is crucial that employees build a shared understanding of the objectives and goals of the organisation, and that they are involved in rapid decision-making processes to contribute to the quality of the decisions taken. Therefore, this study views effective decision-making as occurring at the macro-, meso-, and micro-level in complex and complicated organisational contexts.

Challenges to decision-making for action in complexity: CASs present difficulties for decision-makers because the different levels of the CAS feed different types of information back through the system, producing nexuses of contingencies through multiple levels in the system, resulting in agents constraining each other mutually even when not interacting directly with one another (Salthe, 2012). When faced with real-world complexity, organisational processes unfold to find "good enough" answers in response to questions for which the best answers are unknowable because what people cannot do, they will not do even when highly motivated to do it (Simon, 1996). As Hannan and Freeman (1984, p. 151) point out, "*even when actors strive to cope with their environments, action may be random with respect to adaptation as long as the environments are highly uncertain or the connections between means and ends are not well understood.*"

Simon's (1972) Theory of Bounded Rationality considers the psychology of the decision-maker. Bounded rationality is different from utility-maximising rationality, which assumes that results can be predicted without regard for the decision-making process used by the individual (Simon, 2000). Simon (2000, p. 25) defines bounded rationality as "*the idea that the choices people make are determined not only by some consistent overall goal and the properties of the external world, but also by the knowledge that decision makers do and don't have of the world, their ability or inability to evoke that knowledge when it is relevant, to work out the consequences of their actions, to conjure up possible courses of action, to cope with uncertainty (including uncertainty deriving from the possible responses of other actors), and to adjudicate among their many competing wants.*"

Intentionality: The reasons humans have for their actions are seldom the best rationale and are rarely consistent across the entire range of available choices (Simon, 2000). Despite the cognitive processes of rationalisation, motivation and reflection underlying all human action and relating directly to human intention (Giddens, 1984), "*wisdom varies as the occasion requires*", meaning that human behaviour is contextually and temporally embedded (Juarrero, 2000, p. 24). Human uncertainty about the present and future state of an environment, and their uncertainty about the behaviours of others involved in the context, must be considered if the dynamics of a given context are to be taken seriously (Simon, 2000).

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Sociotechnical organisational routines stem from the agents' interaction patterns, and these emerging and evolving practices intend to, but often fail to, align with managerial objectives (Crick & Chew, 2020). In complex contexts, agility cannot emerge through deliberate intentions and actions, but sensing and utilising opportunities to move the system out of complexity towards a complicated state can enable the organisation to become more agile and resilient (Snowden & Rancati, 2021).

Heuristics and decision-making: Human beings have evolved to continuously assess and scan the environment for problems that must be solved to survive within dynamic contexts: "*How are things going? Is there a threat or a major opportunity? Is everything normal? Should I approach or avoid?*" (Kahneman, 2011, p. 76). Lissack (2019) explains that questioning and understanding ground the enactment of human agency, providing a foundation for taking action. Thus, when we act, we ascribe our will to act to a fleeting "certainty" in recognising and being prepared to act on an available, acceptable choice despite the complexities of the ongoing context (Lissack, 2019). However, uncertainty is ever-present in complex situations and introduces a risk that, due to actor biases, the desired outcomes might not be generated (Tversky & Kahneman, 1974). Furthermore, unintended, undesirable outcomes can emerge from the complex intertwining of human organisation and the technical aspects of IS (Cecez-Kecmanovic et al., 2014). Bolman and Deal (2017, p. 22) advise that when dealing with uncertainty and fearing ambiguity and loss of control, "*develop creativity, risk-taking, and playfulness in response to life's dilemmas and paradoxes, and focus as much on finding the right question as the right answer, on finding meaning and faith amid clutter and confusion.*"

The literal meaning of the word "heuristics" is "the art (or practice) of discovery", derived from the Greek word "heuriskein" that means "to find or discover" (Ulrich, 2005, p. 1). Humans typically use heuristics when they must make decisions based on incomplete information in conditions of uncertainty to address unclear problems for which there are multiple solutions and the probabilities of the potential outcomes are unknown (Gigerenzer & Gaissmaier, 2011). Simon's (2000) decision-making strategy of "satisficing" proposes that agents should strive to find "good enough" answers instead of aspiring to find optimal solutions to problems in uncertain environments. A heuristic can only be effective if it matches the context within which it is applied (Artinger et al., 2015).

Artinger et al. (2015) emphasise the importance of heuristics because their influences traverse organisational hierarchies across the individual and organisational levels. Shared understanding and experience of environmental features spanning organisational levels imply that insights informing heuristics at the managerial level hold value at the individual level and vice versa (Artinger et al., 2015). However, not all agents are perfectly adapted to the given context. Thus, a heuristic is functional, having a particular contextualised purpose, but does not necessarily align perfectly with the real world (Gigerenzer & Gaissmaier, 2011). Nonetheless, heuristics can effectively inform decision-making for enhanced outcomes in complex organisational contexts (Artinger et al., 2015; Schilke et al., 2018).

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The following section used an SLR to investigate heuristics for their influence on dynamic capabilities.

4 MANAGING HEURISTICS TO ENABLE AGILITY IN SOCIOTECHNICAL CONTEXTS

Sociotechnical contexts in organisations are complex and complicated and require effective and coordinated decision-making to achieve agility (Park et al., 2017; Teece et al., 2016). However, despite decision-making processes, agents in such contexts rely on heuristics to enable quick responses to opportunities and threats (Artinger et al., 2015; Schilke et al., 2018). Heuristics are schemata, simple "rules of thumb" that are quick and easy for an organisation's social agents to use, efficiently guide actions, and allow for the flexible adjustment of other actions in real-time across an organisation's strategic, managerial and operative levels (Eisenhardt et al., 2010). Complete knowledge and control for decision-making are not achievable in complex contexts (Artinger et al., 2015; Gigerenzer & Gaissmaier, 2011; Simon, 2000). Because of these challenges to decision-making, and the role of heuristics in complex organisational contexts, a method needs to be developed for the conceptual framework for agility in sociotechnical contexts that considers how heuristics influence dynamic capabilities. In this section, an SLR was conducted to address the second research question:

How do heuristics influence dynamic capabilities in organisational contexts?

4.1 Method: a systematic literature review of heuristics influencing dynamic capabilities

The systematic search and review of literature on heuristics influencing dynamic capabilities in organisations was directly shaped by the keywords contained in the research question: "heuristics" and "dynamic capabilities". The following expression was applied in Scopus to search title, abstract and keyword fields, and limited the results to journal articles in English from the Business, Decision, Computer, and Social Sciences:

```
TITLE-ABS-KEY (
   ("dynamic capabilities")
   AND
   ("heuristic" OR "heuristics"))
   AND
   (LIMIT-TO (SRCTYPE , "j"))
   AND
   (LIMIT-TO (SUBJAREA , "BUSI")
      OR LIMIT-TO (SUBJAREA , "DECI")
      OR LIMIT-TO (SUBJAREA , "COMP")
```

```
      OR LIMIT-TO (SUBJAREA , "SOCI"))
   AND
   (LIMIT-TO (LANGUAGE , "English")
)
```

Articles dealing with statistical or computational heuristics, and articles not relevant to dynamic capabilities and heuristics in organisational contexts were manually excluded.

Figure 3 presents the SLR process that adopted the guidelines proposed by Okoli (2015).

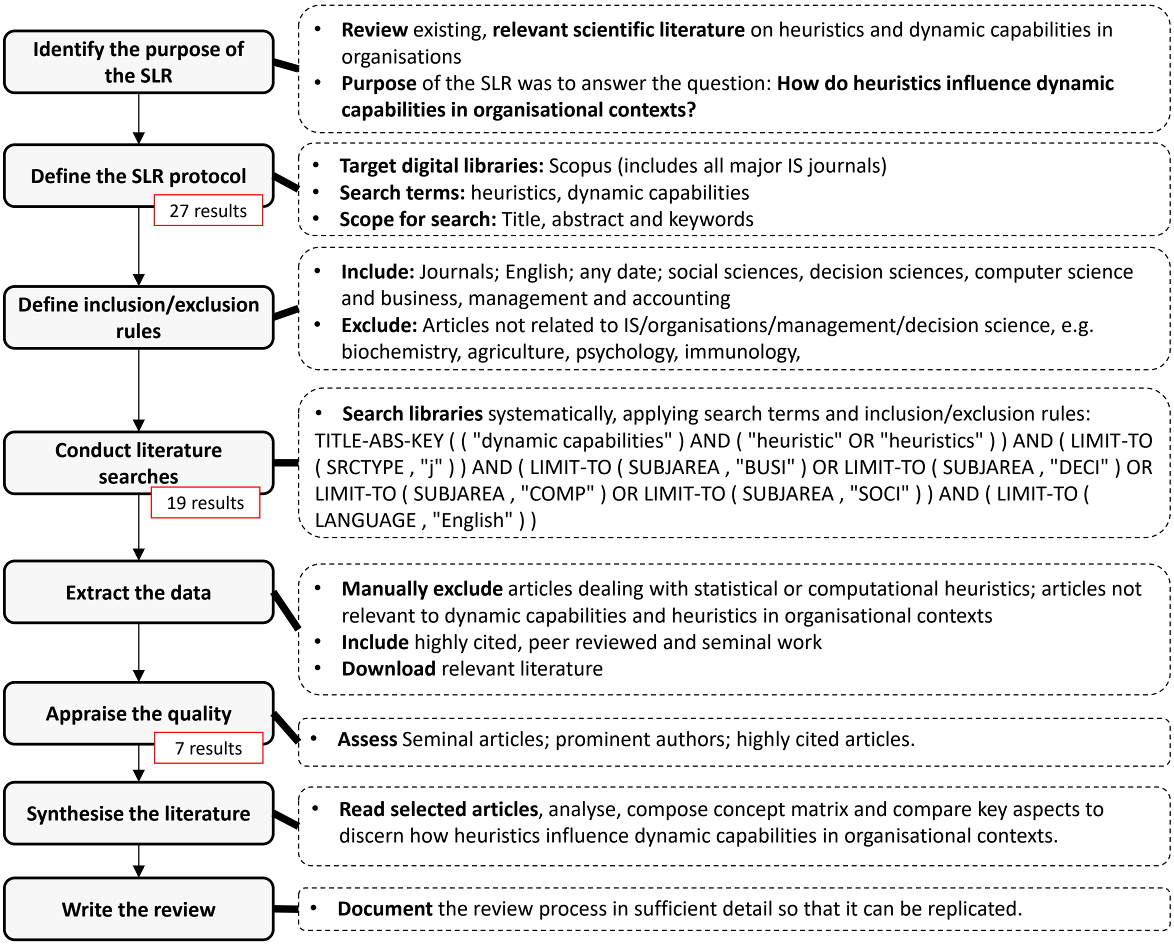

Figure 3: Systematic literature review process to find existing knowledge of how heuristics influence dynamic capabilities in organisations (based on Okoli (2015, pp. 883–884))

4.2 Synthesis and findings

The found articles were reviewed, summarised and synthesised based on the concepts relevant to how heuristics influence dynamic capabilities and agility (see agility features summarised in Table 1 in organisational contexts. Based on the approach proposed by Webster and Watson (2002), the following concepts were identified to create a conceptual structure to analyse the articles' relevance to the research question's topic:

1. the organisational level where heuristics were applied in the article,
2. the purpose, effects and value of heuristics,
3. the implications of using heuristics in decision-making, and
4. dynamic capabilities influenced by heuristics.

The organisational level where heuristics were applied: Five of the seven articles described heuristics as functioning across organisations' strategic, managerial and team/individual levels (Ajgaonkar et al., 2022; Bingham & Haleblian, 2012; Eisenhardt et al., 2010; Espejo, 2015; Nijssen & Paauwe, 2012). Only one of the seven articles considered heuristics at the strategic level and not at the lower levels in the organisation (Bingham & Eisenhardt, 2011).

The purpose, effects, and value of heuristics: Heuristics enable fast organisational learning (Nijssen & Paauwe, 2012), thereby influencing the agility features of speed and competence, and can be practised to develop organisational knowledge and capabilities that can be exploited in the future (Pandza et al., 2003). Bingham and Haleblian (2012) explain that valuable heuristics can be learnt at the overall organisational level from suboptimal outcomes spanning hierarchical and functional levels in the organisation. As experts reflect on and share lessons learned, a collective understanding of organisation-specific heuristics is created instead of depending on individuals' experiential knowledge of heuristics (Bingham & Eisenhardt, 2011) (influencing scalability, flexibility and reusability).

Heuristics are strategically important in dynamic environments as they enable high-performance strategic processes (Eisenhardt et al., 2010). Eisenhardt et al. (2010) further explain that heuristics allow for flexible real-time adjustments to actions in response to events, mitigating organisations' tendency to favour efficiency over flexibility (influencing flexibility and responsiveness). Heuristics are "rational" in unpredictable contexts and, therefore, essential to strategy (Bingham & Eisenhardt, 2011) (enabling leanness and responsiveness). Bingham and Eisenhardt (2011) propose that:

1. organisations learn heuristics explicitly;
2. learnt heuristics have a typical structure across organisations because each type of heuristic addresses a specific aspect of opportunity capture. Opportunity-capture heuristics are "simple rules" of strategic value (enabling responsiveness and scalability);
3. heuristics specific to capturing opportunities are learnt in a particular developmental order by first capturing single opportunities one at a time and progressing to capturing multiple opportunities simultaneously, thus increasing in cognitive difficulty thereby developing expertise through experience; and

4. organisations practice simplification cycling whereby heuristics are pruned and added in a continual fine-tuning process (enabling competence, leanness, reusability and flexibility).

Nijssen and Paauwe (2012) propose that heuristics support organisational agility when effectively applied to identify organisational practices as determinants of organisational agility and to evaluate their ongoing effectiveness in supporting such agility. Heuristics should support a scalable workforce, fast organisational learning, and highly adaptable organisational structures (Nijssen & Paauwe, 2012). Heuristics further support organisational agility by allowing for autonomy, adaptation, and cohesion, enabling self-regulation and self-organisation in organisational systems that must achieve more with fewer resources (Espejo, 2015) (enabling flexibility, responsiveness and leanness). Ajgaonkar et al. (2022) emphasise the importance of heuristics that consider the drivers of workforce agility: external resources available for hire, internal resources available, and pressure to achieve workforce agility.

Implications of using heuristics in decision-making: Heuristics are suitable for most strategic decisions as they involve highly unpredictable situations, high levels of heterogeneity, and actors with limited relevant experience (Bingham & Eisenhardt, 2011) (enabling responsiveness and speed). Managers are the dominant decision-makers in organisations, but often base their decisions on incomplete or incorrect information, thus necessitating heuristics (Nijssen & Paauwe, 2012).

Efficiency (exploiting routines and well-known methods) and flexibility (exploring opportunities presenting novelty) can be balanced through cognitive processing mechanisms practised by groups and individuals (Eisenhardt et al., 2010). Agility comes at the cost of efficiency, and organisations need to develop robust sensing, seizing and transforming capabilities in their management functions so that they may know when and how to manage deep uncertainty (Teece et al., 2016). Eisenhardt et al. (2010, p. 1271) explain that "*[e]fficiency will always be about the quick, economical, mistake-free execution of specific opportunities, whereas flexibility will always be about the fluid, extemporaneous execution of varied opportunities.*" This view reflects Snowden and Boone's (2007) suggestion that different approaches are required for decision-making in complex and complicated situations, respectively. Heuristics enable strategists to balance efficiency and flexibility effectively by applying simple rule strategies in key strategic processes. Managerial reflection, understanding, learning, and attention are required for making decisions and taking actions that balance efficiency and flexibility (Eisenhardt et al., 2010). Pandza et al. (2003) propose that valuable capabilities are not the result of rational decision-making driven by predetermined goals to develop or adopt best practices or improved capabilities. Instead, decisions made using available options are subject to uncertainty due to the incomplete knowledge of decision-makers and the inherent complexity of organisational contexts. Heuristics allow for autonomy in decision-making (Espejo, 2015) and impact the speed of decision-making in strategic processes (Nijssen & Paauwe, 2012). However, heuristics influence the speed

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of, quality of, buy-in for, employee contribution to, and effect of coercive and normative mechanisms on decision-making (Nijssen & Paauwe, 2012). Informal communication enables decision-making through quick discussion and assessment of available options, and promotes learning and adoption of heuristics across groups and hierarchies (Bingham & Haleblian, 2012).

Dynamic capabilities influenced by heuristics: The structures of dynamic capabilities are complex, interrelated and have collective value (Espejo, 2015). Heuristics are essential to effective sensing and responding capabilities in uncertain organisational contexts (Eisenhardt et al., 2010). Dynamic capabilities provide flexibility under conditions of uncertainty (Pandza et al., 2003). Heuristics applied as 'simple rules' are crucial to enabling and developing dynamic capabilities: sensing and responding (opportunity capture) and learning (leaders' ability to learn and develop effective heuristics) (Bingham & Eisenhardt, 2011). Heuristics promote learning from adverse outcomes across organisational levels and functions, and enable coordination at the collective level using informal communication and tacit knowledge (Bingham & Haleblian, 2012) (enabling competence). The experiences of individuals and groups emerge shared heuristics in organisational processes whereby groups and individuals develop distinctive heuristics that exploit their heterogeneous knowledge (Eisenhardt et al., 2010) (enabling competence, reuse and scalability).

Espejo (2015) describes dynamic capabilities as the unfolding outcomes of processes, enabling ongoing improvement of organisational processes. Heuristics enable organisational agility by informing and developing the organisation's sensing, learning, coordinating, and integrating capabilities (Nijssen & Paauwe, 2012). The heuristic framework proposed by Ajgaonkar et al. (2022) promotes sensing, seizing, and continual renewal of capabilities to achieve workforce agility.

4.3 Managing heuristics in organisational contexts

Based on the SLR findings, it was established that heuristics influence organisations' dynamic capabilities, agility features and decision-making to the benefit or detriment of organisational performance. Therefore, developing a conceptual framework for agility in sociotechnical contexts required a practical, scientifically-grounded construct to explain how to manage heuristics for knowing, deciding and acting at the boundaries between complex and complicated sociotechnical contexts for an improved state of agility. It is, therefore, proposed here that a practical technique for effectively managing heuristics in real-world organisational contexts is an integral aspect of a framework for agility in sociotechnical contexts that is relevant and implementable in the real world. To find a suitable method or technique to manage heuristics, critical systems heuristics (CSH), authored by Ulrich (2000), was abductively adopted as a suitable scientific theory, as it explicitly provides "sources of influence" (knowledge, power, motivation and legitimation) as theoretical constructs.

Heuristics are intrinsic to professional practice that deals with qualitative, ill-defined issues, such as what changes would constitute an improvement for an identified problem to be solved for which there is no right or wrong solution (Ulrich, 2005). For example, "achieving agility" is an "improvement" but does not have a "right" or "wrong" solution, as it is subject to variances in stakeholder understanding and intentions of how agility can and should be generated in the ongoing sociotechnical context. The liminal space in the Cynefin framework presents a boundary where the iterative processes of adaption and adoption continuously shift the system to a new state based on agents' decisions and responses (Snowden & Rancati, 2021). CSH is a scientific theory that has its roots in Critical Systems Thinking (CST) and practical philosophy, and includes not only decision-makers but all stakeholders in the process of "critical reflection" on a situation (Ulrich, 2005). CSH is a theory offering a viable approach to "reflective practice" (practising boundary critique) that asks how a "system of interest" (such as a sociotechnical CAS) "ought to be" and how it "actually is" (Ulrich, 2000).

The practice of boundary critique prescribed by CSH (Ulrich & Reynolds, 2020) arguably offers a practical technique for managing heuristics in sociotechnical contexts for favourable agility outcomes because it aims to identify the sources of influence and related boundary judgements that underlie agents' heuristics that can move a system towards an improved state. This approach allows the stakeholders of the "system of interest" to negotiate how the system can be moved towards an improved state, for example, improved agility in sociotechnical contexts.

Figure 4 summarises the boundary categories and critique questions defined for this study of agility in sociotechnical contexts based on Ulrich (2000) and Ulrich and Reynolds (2020).

Boundary judgements, as adopted in this study for their influence on agility in sociotechnical contexts, comprise four categories, as shown in Figure 4:

1. **sources of motivation** relate to the agents' impetus based on what they are motivated to effect, with or without intent;
2. **sources of power** relate to control based on what empowers, overrides and guides the agents;
3. **sources of knowledge** refer to agents' abilities and resourcefulness to do what can or should be done; and
4. **sources of legitimation** relate to the amplitude of agents' stakeholder perspective. Boundary judgements underlie agents' heuristics, influencing their actions in a system of interest.

The concept in CSH of "moving the system to an improved state" (Ulrich, 2000) aligns with the Cynefin framework's concept of "moving to a more favourable adjacent possible state" at the boundaries where key decision points can transition the system between the complex and complicated domains (Snowden & Rancati, 2021). In addition, agents' sense-making processes and their responses to governing (context-free) constraints (in complicatedness) and enabling (context-sensitive) constraints (in complexity) can be improved because practising boundary critique brings an understanding of the underlying boundary judgements that agents are using in their heuristics. Through this approach, the practice of boundary critique can change the

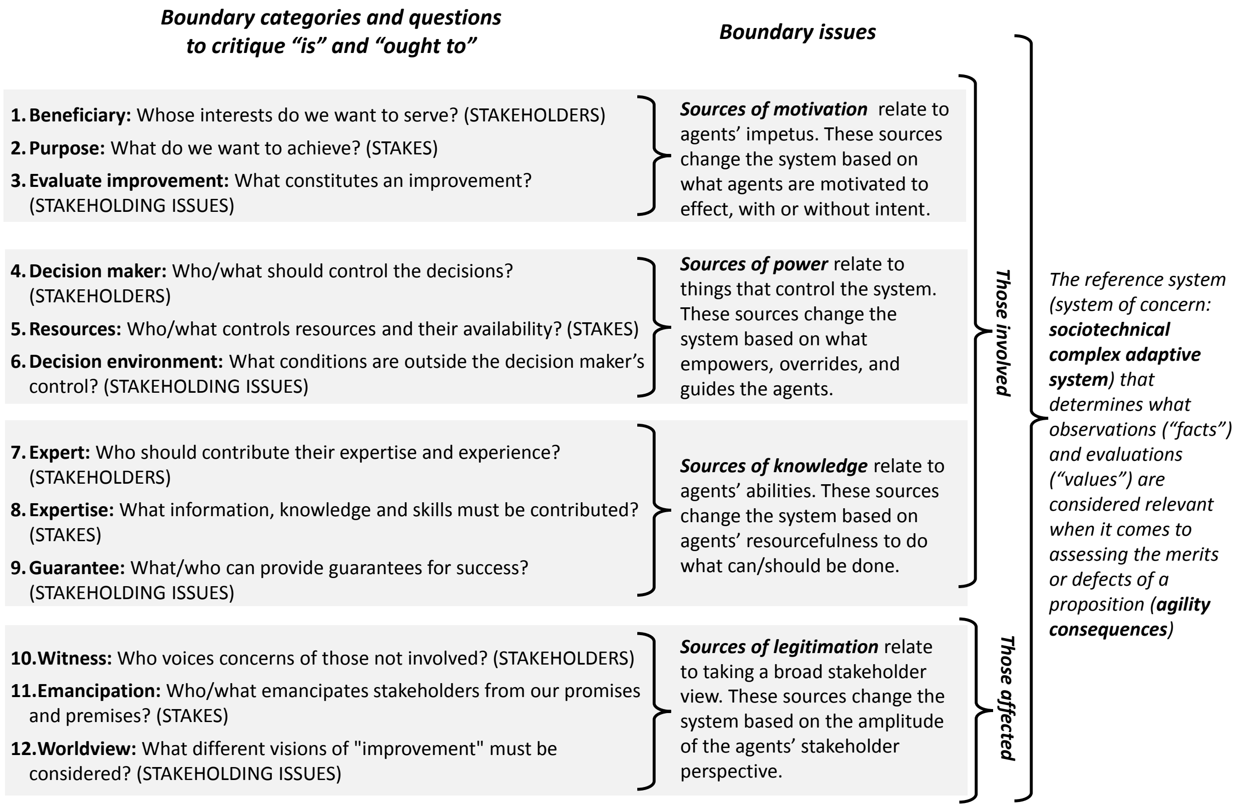

Figure 4: Boundary categories and questions for practising CSH boundary critique in a sociotechnical CAS (based on Ulrich (2005, p. 10); Ulrich and Reynolds (2020, pp. 256, 290)

quality of the system's interactions iteratively by influencing how agents sense, learn, coordinate and integrate, thereby continuously providing opportunities to move the system at the micro-, meso- and macro-levels towards a more favourable agility state. Therefore, this study proposes the practice of boundary critique from CSH as a practical technique to identify the underlying boundary judgements to manage the heuristics that influence actions (governed by dynamic capabilities) with emerging and evolving agility outcomes and consequences.

5 A CONCEPTUAL FRAMEWORK FOR AGILITY IN SOCIOTECHNICAL CONTEXTS

In organisational and IS science, sensing and responding are the overarching concepts for achieving agility in organisations (Park et al., 2017; Sambamurthy et al., 2003; Tallon et al., 2019). The Cynefin framework explains how effective decision-making in complex and complicated contexts can transition the CAS towards improved outcomes from the sensing and responding capabilities and actions of the organisation's agents (Snowden & Boone, 2007).

This study of the dynamics of agility in sociotechnical contexts defines thriving agility as the sustained functional emergence and evolution of constraints that iteratively create and enhance agility features. In contrast, faltering agility is defined here as the emergence and evolution of constraints that iteratively disintegrate agility features with consequential loss of the system's overall agility coherence.

Continuous adaptation iterations across levels in the system emerge non-repeatable agility, whereas iterations of adoption across levels in the system evolve repeatable agility as patterns stabilise (Eisenhardt & Martin, 2000; Juarrero, 2000; Snowden & Rancati, 2021). Both thriving and faltering agility can emerge and evolve intentionally or unintentionally. The constraints form and shape the behaviour of the CAS (Holland, 2002) and are those things that govern, enable or cause tension in the coordination and integration (Teece et al., 1997) of agents' activities. CSH provides a theoretical keystone that enables an empirical investigation of how heuristics can influence interactions to change the system's agility state during phase-shifting between complicated and complex contexts in such a way as to continuously emerge and evolve favourable agility features in a sociotechnical CAS.

A model: Figure 5 presents the model of the proposed conceptual framework for agility in sociotechnical contexts. As found in the two SLRs conducted for this study, the dynamic components of agility in sociotechnical contexts interact across three levels:

1. The **macro-level** represents complex and complicated sociotechnical contexts and is based on the Cynefin framework, underpinned by CAS theory, with transitions through key decision points at the complex and complicated domain boundaries.
2. The **meso-level** represents the oversight/managerial level (managing and governing activities), comprising the dynamic capabilities of sensing, learning, coordinating and integrating in complex and complicated sociotechnical contexts.
3. The **micro-level** is where heuristics influence how activities are being/should be done for improved agility. The practice of boundary critique, adopted from CSH, explains how sources of influence, revealed in agents' boundary judgements, influence agility outcomes and consequences as thriving or faltering agility features in complex and complicated sociotechnical contexts.

The iterations of the sociotechnical agents' continuous actions, interactions and heuristics have outcomes and consequences for agility in sociotechnical contexts. In the top part of the model presented in Figure 5, iterations in complex sociotechnical contexts are represented by multiple dashed, dispersing lines, illustrating the dissipative, discontinuous and dispositional nature of complexity. In contrast, the bottom part of the model shows the more predictable, governable and repeatable nature of complicated contexts as solid-lined iterations. Transitions between complexity and complicatedness occur when heuristics, undergirded by boundary judgements, influence the sociotechnical agents' dynamic capabilities, resulting in intended outcomes and unintended consequences for the overall agility of sociotechnical contexts.

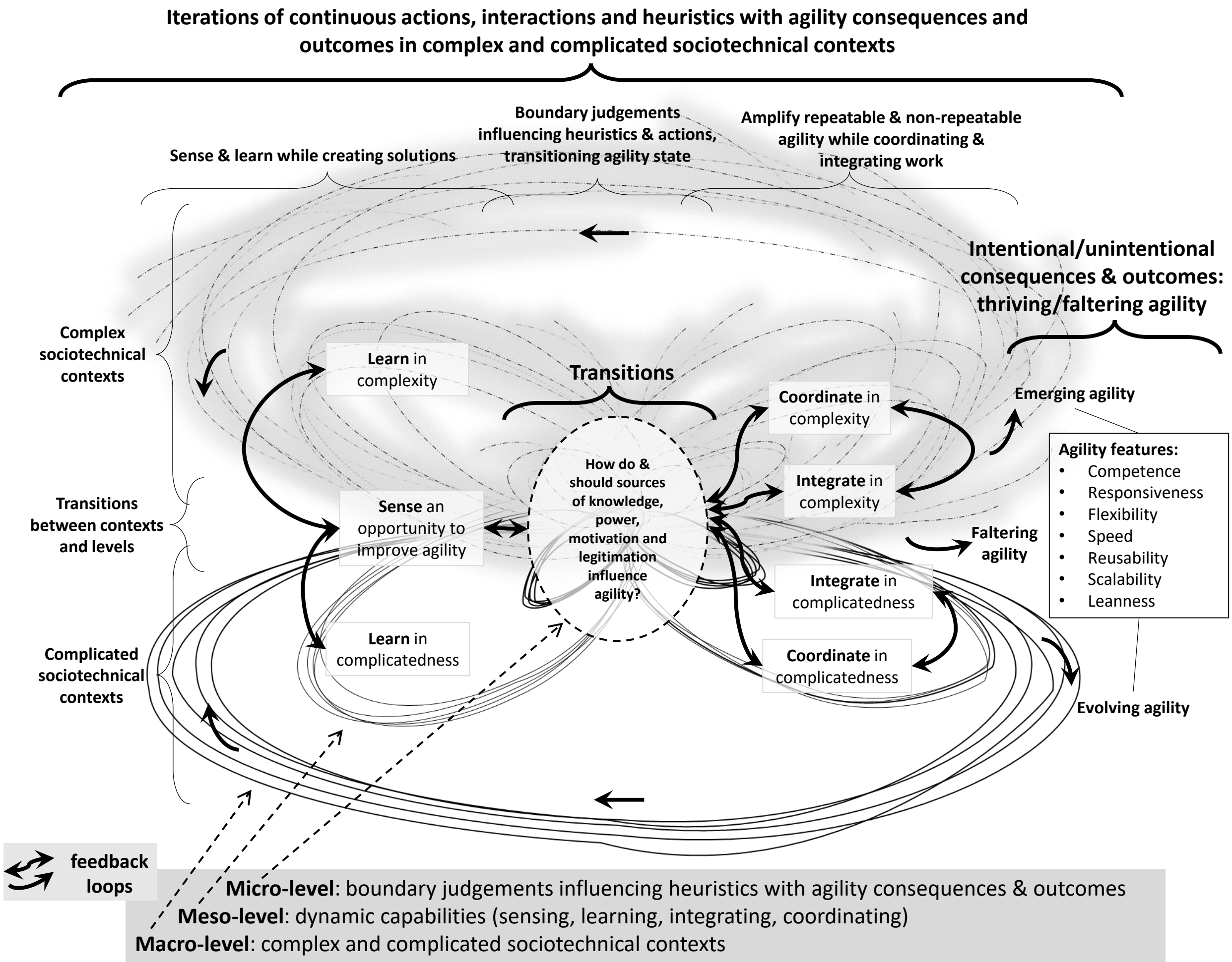

Figure 5: A conceptual framework for agility in sociotechnical contexts (based on Kurtz and Snowden (2003); Lillie et al. (2023); Salthe (2012); Ulrich and Reynolds (2020))

A method: Practising boundary critique at the liminal boundary between complexity and complicatedness provides a mechanism to evaluate the next thing to do that would amplify the emergence and evolution of agility features in sociotechnical contexts. By practising boundary critique, the agents involved must then use the opportunity to consider what can and should change in the subsequent work iterations to amplify the desired agility features in sociotechnical contexts, locally and collectively. Boundary judgements can be revealed by collaboratively asking and critiquing the answers to the 12 questions (see Figure 4) in the "is" (descriptive) and "ought" (normative) modes. However, these questions can only be meaningfully asked and answered in a real-world context and represent context-sensitive and context-free constraints because of their potential to influence the system towards thriving agility consequences and outcomes (Juarrero, 2000; Ulrich, 2000).

Additionally, there is no theoretical limit to the size of the sets of possible answers for each of the 12 boundary questions. It is, therefore, prudent to test the use of boundary critique as defined by CSH theory in a real-world sociotechnical context to further develop and refine the proposed conceptual framework for agility in sociotechnical contexts. Practising boundary critique presents opportunities to discover "unknown unknowns" (in complexity) and to question and debate "known knowns" (in clarity) and "known unknowns" (in complicatedness) (Snowden & Boone, 2007), thereby taking a broader, contextualised view of what can or should be coordinated and integrated to influence improved agility consequences and outcomes. For example, possibilities for reuse, scaling or repurposing might be overlooked when imposing a deterministic linear process on a sociotechnical context at hand because opportunities for discussions are closed down *a priori*.

6 FUTURE RESEARCH

The conceptual framework for agility in sociotechnical contexts was developed by starting with the structural components of the conceptual model of agility in IS proposed by Lillie et al. (2023), and then conducting two SLRs that incorporated scientific literature and the well-established theories of CAS (Holland, 1992), dynamic capabilities (Teece et al., 1997) and critical systems heuristics (Ulrich, 2000) to explain the dynamic components of agility in sociotechnical contexts. By using the framework's structural and dynamic components as units of analysis, future research could apply the proposed conceptual framework for agility in sociotechnical contexts to case study research to test and further develop the framework for its practical application in organisations. Such research could refine the conceptual framework, and develop a practical framework for achieving agility in a specific sociotechnical real-world context. Alternatively, action research could offer an effective method to apply the proposed conceptual framework to a real-world context because action researchers work with practitioners to address a significant practical problem (Järvinen, 2007).

Due to the generalisability of CAS (Holland, 1992), dynamic capabilities (Teece et al., 1997) and critical systems heuristics (Ulrich, 2000), the ubiquitousness of decision-making in organisations (Kurtz & Snowden, 2003), and the broad consensus in IS research that sociotechnical contexts are complex (involve uncertainty) and complicated (require expertise) (Crick & Chew, 2020; Gregor, 2009; Park et al., 2017), the proposed conceptual framework could potentially be used to study emergent phenomena other than agility in sociotechnical contexts. However, it should be noted that the proposed framework is conceptual and has not been tested in real-world contexts.

7 CONCLUSION

The research problem was identified using the existing scientific literature that indicated that organisations require their IS to be agile. Furthermore, current scientific knowledge of how organisations can achieve agility in their sociotechnical contexts is insufficient. The contribution of this study is a conceptual framework for agility in sociotechnical contexts that aimed to address this identified problem. The framework was developed by conducting two SLRs using Scopus. Scopus is recognised as the largest abstract and citation database of peer-reviewed research literature. However, despite the vast number of peer-reviewed articles indexed in Scopus, the risk remains that some important, relevant work was inadvertently excluded from this study. Thus, a limitation of this research is that Scopus was the only database used for data collection in the SLRs.

The two SLRs synthesised the literature, incorporating CAS (Holland, 1992), dynamic capabilities (Teece et al., 1997) and critical systems heuristics (Ulrich, 2000) to integrate the structural and dynamic components of agility in IS to produce a conceptual framework for agility in sociotechnical contexts. The first SLR investigated frameworks that enable organisational agility. Consequently, the Cynefin framework was adopted to explain the dynamics of contextualised decision-making and agility. The second SLR identified the influence of heuristics on decision-making and dynamic capabilities. This research contributes to the further understanding of agility in organisations and how organisations could achieve agility.

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Research Article

Factors that influence computer programming proficiency in higher education: A case study of Information Technology students

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ABSTRACT
The industrial world has witnessed an increased demand for computing based skills due to the advent of robotics, artificial intelligence, and analytics. However, the learning of computer programming is challenging and requires an intensive cognitive effort to attain a high degree of skill and expertise. Given this phenomenon, this study undertook to ascertain the factors that influence proficiency in computer programming. The study adopted a quantitative approach and a survey research strategy, guided by a conceptual model. A survey questionnaire was designed as the primary source of data collection. The respondents comprised students who were enrolled for Information Systems and Technology (IT) courses at a higher education institution. The main factors that were identified as significant predictors of computer programming performance were Problem-Solving Ability and Self-Efficacy. The findings contribute to enhancing computer programming pedagogy, which could lead to enhanced student performance in assessment, and validation of the conceptual model.

Keywords Computer programming performance, Intrinsic and extrinsic motivation, Learning styles, Self-efficacy, Problem-solving ability

Categories • **Social & programming topics** ∼ **Professional topics** • **Computing Education** ∼ **Computer science education/Information Technology/Information systems**

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1 INTRODUCTION

The industrial world has witnessed an increased demand for computing based skills, particularly in the domain of computer programming. The demand for computer programming expertise has been elevated by the emergence of the 4th Industrial Revolution (4IR), which

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has compelled members of society to become intelligent users of technology. Technological intelligence is embedded in 4IR systems such as robotics, data analytics and artificial intelligence (AI) by virtue of computer programming logic. The specific demand is for skills that translate to job roles such as business analytics, data analytics, project management, computer programming and testing, systems analysis and design, and database and network administrators (Abdunabi et al., 2019). The demand for these skills is expected to escalate by 13% in the period from 2016 to 2026 (Abdunabi et al., 2019). Central to all of these job portfolios is either a deep or conceptual understanding of computer programming. A multitude of factors, including inherent interest, financial stability and the need for acquiring IT expertise have propelled an increasing number of students to register for technology-oriented courses that provide a substantive exposure to computer programming content (Kori et al., 2015). The rise in student enrolments for technology related courses has, unfortunately, been paralleled by an increase in poor performance and failure in these courses. Students have consistently performed poorly in programming assessments at the higher education level and university courses with programming involved in the curricula have also experienced significantly high dropout rates (Luxton-Reilly et al., 2018). A large number of institutions recorded high rates of failure in introductory programming courses (Konecki & Petrlic, 2014; Peng et al., 2017).

It is within this context that the economic sector requires that graduates who are proficient in computer programming, thereby enhancing their employability and ensuring they add value to the sustained imperative to embrace 4IR technologies. Currently, academic studies have not been conclusive or convergent in their attempts to ensure that cognisance is given to a core set of factors that will allow students to acquire proficiency in computer programming. To address this gap, this article seeks to answer the following main research question: "What are the factors that influence proficiency in computer programming at the higher education level?"

2 LITERATURE REVIEW

Quality in the field of teaching and learning, and specifically e-learning, has become of paramount importance for academic staff and students (Pawlowski, 2007). It has been established that academic performance in computer programming requires a significant cognitive effort from students. However, there are many factors that contribute to this cognitive load and an understanding of these factors is pivotal to ensuring that the failure rates in computer programming modules is reduced. The factors that influence the proficiency of computer programming are diverse and range from demographic variables, such as gender and programming experience, to psychological variables, such as intrinsic and extrinsic motivation to learn computer programming. This constellation of factors provides the basis for the discussion that follows.

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2.1 Self-Efficacy in Computer Programming

Self-efficacy (SE) is described as a person's evaluation of their inherent abilities and skills and whether or not their competencies can be used to deliver outcomes that bear a positive effect on their community (Bandura, 1977). According to this definition, SE refers to an individual's confidence in their ability to produce a desirable outcome. Attitude towards the subject matter and SE are among the most important factors in determining one's success in a particular field (D. W. Govender & Basak, 2015). A study involving 83 secondary school students conducted by Kallia and Sentance (2019) established that those students who did not understand the functions of some core programming statements rate lower in self-efficacy as compared to students who understood these statements well. Students who faced difficulties earlier on in their experience with programming are more likely to adopt an overall view of computer programming as being inherently difficult. There is a strong link between SE in problem solving and SE in computer programming, suggesting that students who have confidence in their problem-solving ability tend to perform better in computer programming tasks (I. Govender et al., 2014).

A study conducted with 433 programming students reported a strong correlation between students' programming SE and their sense of satisfaction and interest in the module, which was also linked to students' performance in an introductory programming module (Kanaparan et al., 2019). Teachers should, therefore, pay attention to their students' SE rates/levels because the theory states that the more SE a person has, the more resilient they will be with regard to challenges and obstacles faced in computer programming. A study conducted with 214 computer science students at 3 different universities assessed students' self-assessments when encountering different programming practices such as getting a syntax error or planning (Gorson & O'Rourke, 2020). The study also looked at the students' mental imagery of the competence required to be a professional programmer and found that students who believed that they could not acquire this level of competence had low levels of SE, resulting in poor performance in computer programming assessments.

2.2 Programming Experience

Learning programming is very much about learning by doing. Students who have had previous experience with learning programming, through high school classes or their own independent efforts, perform better in programming courses at university (Kori et al., 2016; Lishinski et al., 2016). Students in one study who had previously taken a programming course, perhaps in high school, had a significantly easier time reading and understanding the programming language as compared to first-time programming students (D. W. Govender & Basak, 2015). It has been demonstrated that students with previous knowledge or engagement with computing programming have a higher level of SE towards computing skills (Kolar et al., 2013). This shows that Programming Experience can positively affect SE as it gives students an idea of what to expect. Such knowledge would increase their confidence going into a computer programming course at a higher education institution. The greater the Programming Experience of students, the higher their level of programming SE (Kittur, 2020). These findings suggest that getting students involved with programming from their schooling years will support their SE in programming-related courses (Kittur, 2020).

2.3 Intrinsic and Extrinsic Motivation

The construct of motivation can be categorised into two broad categories, namely, intrinsic motivation (IM) and extrinsic motivation (EM) (Ryan & Deci, 2000). IM refers to a person who is motivated to do something because they get enjoyment and pleasure from doing that task. EM means that a person is motivated to do something because of the outcome they will receive or to avoid a negative consequence. A study by Gottfried (1985) found that intrinsically motivated students had more academic success than extrinsically motivated students. IM and EM are significant factors that determine performance in computer programming because of the inherent nature of programming itself (Tavares et al., 2017). According to Fang (2012), students who experience excess amounts of difficulty in programming may have low levels of self-efficacy, which also reduces their motivation towards the subject; nevertheless, their motivation can increase with aspects of programming that they do find enjoyable. Most students in this study said that, in particular, they enjoyed learning programming through using robotics as it felt like a fun activity rather than learning a skill (Fang, 2012). It has also been found that students who had previous knowledge and engagement with computer programming displayed more EM than students with no programming experience (Aivaloglou & Hermans, 2019).

In another study (Yacob & Saman, 2012), programming students were found to have two main sources of IM, namely, attitude and setting themselves stimulating goals. The aspect of attitude tended to come from the student's prior experience with programming and whether or not the current programming content that they learnt met their expectations. The extrinsic factors that were found to motivate students were "clear direction, reward and recognition, punishment and social pressure and competition" (Yacob & Saman, 2012, p. 426). Each of these factors were found to positively contribute to students' motivation to engage with the programming content. The effect of gamification on students' motivation and performance in programming was the focus of another study (Khaleel et al., 2019), which found that gamification exploits the EM that all humans naturally possess and uses this motivation to make learning less boring and more satisfying and rewarding. Andriotis (2014) reports a majority (80%) of student respondents as saying that they would enjoy their higher education studies more if game-like elements were included in the courses, and 60% reported that their motivation would increase if their university displayed leader boards as this would encourage more competition between their peers and themselves.

2.4 Problem-Solving Ability

Problem-solving abilities required in mathematics are very similar to the cognitive skills required in computer programming. The syntax of a computer programming language coupled with the semantics of the logical rules and data structures provide the theoretical foundation for problem solving. There is a correlation between problem-solving ability, the mental model of the problem domain and computer programming performance (Lishinski et al., 2016) This finding applied to the advanced aspects of computer programming, where the students had to develop a fully-fledged computer programming solution to a real-life problem. The role played by the syntax and semantics of computer programming code has been explored in a phenomenological study (I. Govender, 2021) which focused on the difficulties that novice programmers face when they learn to program. In order to enhance the mental model visualisation of the problem domain, what is important is a "scaffolding" approach to the teaching of computer programming that entails a strong focus on baseline knowledge involving computer programming language syntax and an inculcation of a deep understanding of data types and structures (I. Govender, 2021). Once these fundamentals have been entrenched, students will be cognitively prepared to engage in incremental learning that involves algorithm development and problem solving. These learning challenges have been documented by various studies: one (Robins et al., 2006) highlighted the difficulties faced in learning looping and arrays; one (Goldman et al., 2008) noted the problems students face with learning inheritance; and one (Garner et al., 2005) alluded to the abstractionism inherent in understanding how a constructor instantiates an object of a class.

Some authors have stressed the importance of problem-solving ability as a crucial factor in enhancing algorithmic thinking capacity (Malik et al., 2019; Romero et al., 2017). Algorithmic or computational thinking has been defined as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2008, p. 3717). A study conducted with 113 Information Technology and Engineering students at a university found that, when students spent additional time on improving problem-solving skills, this had a positive effect on their perceived ability to learn programming (Lawan et al., 2019). Another study (Kinnunen, 2009), comprising interviews with five computer science lecturers at a university about the reasons for students' poor performance in programming courses, found that all five agreed that students tend to lack the fundamental skills needed for analysing and solving a problem. A preliminary study (Bain & Barnes, 2014), which questioned students on the challenges experienced when learning how to write computer programming code, demonstrated that 50% of the students did not have a strategy for dealing with problems that arose while writing the code. The main method of trying to solve the problem was to turn to Internet searches. It was also found that 53% of students did not understand how different programming concepts and elements of code related to the bigger picture and how small sections of programming topics connected with others to form a whole solution to a problem. The study concluded that the fundamental issue with learning programming was inadequate problem-solving methods and a lack of critical thinking. It has been recommended that, before students begin to engage in computer programming assessment tasks, they should have foundational knowledge of problem-solving strategies and procedures (Loksa et al., 2016).

2.5 Deep and Surface Learning

The approach that students adopt towards learning has been a topic of extensive research pertaining to higher education (Lonka et al., 2004; Trigwell et al., 1999; Vanthournout et al., 2013).

A study (Marton & Säljö, 1976) introducing the concepts of a deep learning and a surface learning approach found that students who tried to obtain a genuine understanding of the academic material had a deep approach to learning. This type of student attaches personal value to the concepts and knowledge gained in class. Students who, on the other hand, use memorisation and rote learning techniques rather than understanding to pass tests and examinations are said to adopt a surface learning approach (Spada & Moneta, 2012). Students who have a surface approach to learning may be able to pass and even excel in a subject; however, their learning style is appropriate only in test and examination situations where they are required simply to reproduce information and, in situations where they are required to apply this information in a practical way, they usually fall short. Students using a deep approach to learning apply critical thinking skills, thereby enabling them to make connections between different concepts more easily (Lindblom-Ylänne et al., 2019). There is a link between the surface learning approach and SE: students with low SE, low motivation to study and negative beliefs about studying tended to use the surface approach to learning (Lindblom-Ylänne et al., 2019). Students who participate more in class activities and adopt a positive attitude towards computer programming will tend to engage in more deep learning techniques (Floyd et al., 2009). In a study that entailed the interviewing of 177 university students who enrolled in a programming module, it was established that students who scored high on deep learning attributes also achieved high marks for their computer programming module (Fincher et al., 2006).

Students can be encouraged to engage in deep learning strategies by being assessed through project work instead of only being assessed through written examinations (Peng et al., 2017) Moreover, through project work, educators can better monitor and aid students to identify their weaker areas more efficiently (Peng et al., 2017). There is agreement that programming needs to encompass both deep and surface learning approaches because of the fact that programming is more of a skill than knowledge (Konecki & Petrlic, 2014). Teaching students problem-solving skills and strategies will encourage students to adopt deep learning techniques because it is the ability to analyse a problem and converge on a solution that comprises a deep learning approach (Malik et al., 2019). One study (Ranjeeth, 2011) found that 50% of computer programming students at higher education institutions tend to adopt a surface learning approach for computer programming in introductory courses. The researcher suggests that students tend to adopt this style of learning to meet the course requirements and to be able to obtain a pass mark for programming assessments. Hence, the adoption of deep and surface learning in computer programming does become a factor that needs to be examined in greater detail in terms of its influence on students' performance in computer programming assessments.

The literature review has been designed to provide a comprehensive coverage of the main topics that prevail in this domain of study. The broad classification of topics, namely self-efficacy, programming experience, intrinsic and extrinsic motivation, problem-solving ability and learning styles, covered in the literature review led to the development of the conceptual model illustrated in Figure 1 to guide the data collection phase of the current study. The next section covers the methodology adopted for the study.

3 METHODOLOGY

A quantitative approach was adopted for this study (Saunders et al., 2009) This decision was based on the observation that many of the correlation-based studies on the factors that influence academic performance in computer programming have been conducted using a quantitative approach and a survey type of methodology.

3.1 Conceptual Model

The study's conceptual model depicted in Figure 1 was constructed on the basis of the factors that have been hypothesised to influence performance in computer programming. The factors identified in Figure 1 were adopted from a range of studies (Bandura, 1977; Fang, 2012; Gottfried, 1985; Kori et al., 2016; Lishinski et al., 2016; Spada & Moneta, 2012).

In Figure 1, the independent variables are Programming Experience, Problem-Solving Ability, Learning Styles (Deep and Surface) and Intrinsic and Extrinsic Motivation. According to the literature reviewed, Programming Experience and Problem-Solving Ability have a direct influence on a student's SE regarding computer programming, and this manifests in a student's ability to learn computer programming. The Learning Style adopted by a student in terms of deep and surface learning also has a direct influence on academic performance in computer programming, as do IM and EM. According to Yacob and Saman (2012) both Intrinsic and Extrinsic Motivation have a positive relationship to the learning of computer programming. While it has been established that Programming Experience and Problem-Solving Ability have an influence on performance in computer programming, these influences are mediated by SE.

The dependent variable in the study is the students' proficiency/academic performance in computer programming. This variable was measured by obtaining a self-assessment-based rating of students' performance in computer programming assessments. The students in the Information Systems and Technology (IS&T) discipline at the University of KwaZulu-Natal (UKZN) undertake formal practical assessments where they are required to use their programming skills to display their proficiency in computer programming and provide a successful solution for the task given to them. It was envisaged that the mark obtained by the students

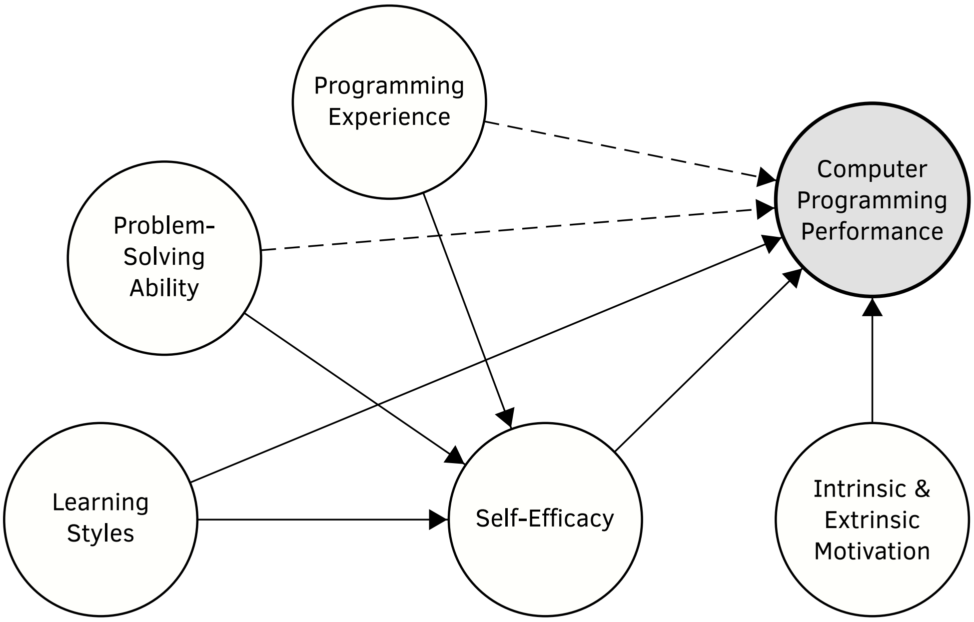

Figure 1: Conceptual model

would provide a guideline to enable the students to rate their individual performance in computer programming assessment. This self-reported rating is used as an indicator of the students' academic performance in computer programming. The strategy of using practical computer programming assessment activity as an indicator of proficiency in computer programming has been used in studies with a similar purpose to that of the current study (Bennedsen et al., 2007; Edwards et al., 2019). SE in computer programming is theoretically linked to a students' background and previous exposure to programming as well as their background in mathematics and problem solving (Abdunabi et al., 2019). A student's level of SE is also related to their learning style because students with higher SE are more likely to adopt a deep learning style as they tend to find the subject inherently interesting. Finally, the overall combination of each of these factors, SE, Learning Styles, Programming Experience, Problem-Solving Ability and Motivation is envisaged to result in a student's achieving higher marks in programming tests and examinations. The results of tests, and examinations then feed back into their SE, if they have performed well in a test or examination, and this will work to increase their belief in themselves and their programming abilities, which then results in them consistently performing well on tests and examinations. Both IM and EM have a positive relationship to the learning of computer programming (Yacob & Saman, 2012). Also, students who find the subject more enjoyable will develop both IM and EM to work on programming tasks, thereby ensuring that they are adequately prepared for examinations and assignments pertaining to computer programming.

3.2 Study Design

The site for the study was the Pietermaritzburg and Westville campuses of UKZN. Due to the adoption by the university of online learning, the launch of the study questionnaire was conducted during online lecture and practical sessions on the Microsoft Teams (3rd year, Honours and Masters programmes) and Zoom (2nd year) video conferencing platforms.

The population for the study comprised all Information System and Technology (IS&T) students that were enrolled for a computer programming module. The population consisted of 2nd and 3rd year IS&T students, as well as Honours and coursework Masters students. The total population of the study was 420 university students from the IS&T discipline. A census approach was adopted where the sample size chosen for the study was also the total population of the study, which was 420 students.

This study employed a structured, survey questionnaire as the primary source of data for the study's empirical analysis (Sekaran & Bougie, 2016). The questionnaire was designed to resonate with the study's conceptual model. Construct validity refers to the alignment between the constructs of the study (which are referred to as unobservable variables specified at a conceptual level) and the questionnaire items that are used to obtain a tangible measure of that construct (Peter, 1981). A viable strategy to ensure construct validity is to align questionnaire items to previous studies where these constructs and items have been validated. The study's main constructs were subjected to theoretical validation by using previous research efforts with a similar objective and also included constructs identified in the study's conceptual model. Table 1 provides a summary of the sources of the questions measuring the constructs in the questionnaire.

Table 1: Summary of the sources of questionnaire items

Construct	**Reference**	**#items**
Self-Efficacy	Askar and Davenport (2009)	12 items
Learning Styles	Mahatanankoon and Wolf (2021)	6 items
Motivation	Amabile et al. (1994)	8 items
Problem-Solving Ability	Tukiainen and Mönkkönen (2002)	10 items

The questionnaire was discussed with academics involved in the teaching of computer programming in the IS&T discipline at UKZN. Comments and suggestions were then incorporated into the questionnaire. The questionnaire was piloted with two IS&T Masters students and two students from the IS&T Honours class.

The questionnaire was launched during formal online lectures by the academic staff members who were lecturing in the 2nd year, 3rd year, Honours and Masters programmes. Students were informed of the requirements regarding the questionnaire and were provided with an opportunity to complete it during the computer programming practical sessions. The questionnaire was made available as an online survey. Students were required to answer programming related tasks to demonstrate their comprehension of conditional, logical and data structure-oriented problems during their computer programming practical sessions at the University. Students were given the latitude of completing these questions without any time restrictions.

Ethical clearance and gatekeeper applications were obtained prior to the data collection phase. In terms of the survey protocol, the study respondents were informed of their voluntary participation in the study and in compliance with the Personal Protection of Information (POPI) Act, no personal information was collected that could be used to directly identify the study's respondents. The anonymous nature of the survey meant that computer programming performance would be a self-assessment rating, which was useful for estimating the construct of academic performance. This self-reported measure of academic performance in computer programming was validated against the respondents' Problem-Solving Ability in the context of computer programming tasks.

The two main statistical methods used were descriptive and inferential statistical analysis. The descriptive statistics used comprised measures of central tendency (mean and median), measures of variability (standard deviation) and frequency distribution. The descriptive results are displayed by stacked bar graphs and histograms. These data visualisation techniques were used to provide an overall view of the empirical evidence with regard to the study's main constructs such as Programming Experience, Problem-Solving Ability, SE and Computer Programming Performance in a formal computer programming assessment. The routine check for data reliability was conducted via the Cronbach alpha test. The inferential statistics used were the one sample t-test, tests of normality, the Pearson Correlation Co-efficient and multiple regression analysis.

4 RESULTS AND DISCUSSION

The primary data collection instrument consisted of a questionnaire that comprised two main sections. The first section (labelled Section A) consisted of demographic questions and questions pertaining to levels of experience in the domain of computer programming and systems analysis and design. The second section of the questionnaire comprised the core aspects that addressed the main objectives of the study (see Table 2). There were 133 valid responses received, constituting a response rate of 32% .

Table 2: Second section of the questionnaire

Section label	Response type	Concept	#items
Part One	Likert scale	Intrinsic and Extrinsic motivation	8
Part Two	Likert scale	Learning styles	6
Part Three	Likert scale	Self-Efficacy	12
Part Four	MCQ	Problem-Solving Ability and Computing Mental Model	10

4.1 Demographic and Background Information of Participants

Section A of the questionnaire was designed predominantly to obtain demographic and background information from the study respondents. The demographic data pertaining to the level of study is presented in Figure 2.

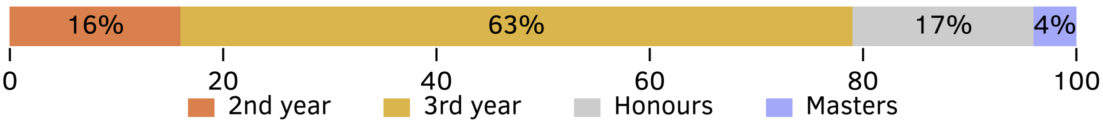

Figure 2: Level of study

Figure 2 illustrates that the majority of the respondents (63.16%) were in the 3rd level of undergraduate study, followed by Honours level (16.54%), 2nd level of undergraduate study (15.79%) and Masters (4.51%) level of study. First year students registered for IS&T modules were not included as part of the target population as students in their 2nd year of undergraduate studies may enroll for the module focusing on Introductory Programming for Information Systems. The largest group of the respondents (79.7%) comprising 3rd year and Honours students were in their respective exit levels, which would give an indication of their preparedness for employment in the computer programming sector.

The academic college of affiliation of the study's respondents is presented in Figure 3 showing that 64% of the respondents were from the College of Law and Management Studies (LMS) and 36% from the College of Agriculture, Engineering and Science (AES).

Figure 3: College of Affiliation

A summarised view showing an approximation of the years of computer programming experience acquired by the study's respondents is provided in Figure 4. The majority of the study's respondents were affiliated to the College of Law and Management Studies (LMS), and given the IS&T curriculum specifications, students from the College of Agriculture, Engineering and Science (AES) will in all probability have greater previous experience of computer programming engagement.

The majority of respondents, that is 44.4% had between 0- and 2-years' experience, while 31.6% had between 2- and 3-years' experience, followed by 18% who had between 3- and 4-years' experience and lastly 6% who had more than 4 years of experience in computer programming. These results are consistent with the College of Affiliation results, as AES students undertake computer programming in the first year of their undergraduate curriculum whereas

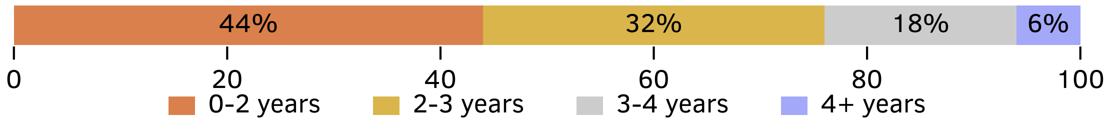

Figure 4: Computer programming experience

BCOM students undertake an introductory programming module in the second year of their undergraduate studies. Respondents that reported more than 4 years of computer programming experience would include students that have computer programming exposure at high school level and students undertaking the Masters qualification.

4.2 Tests of Normality

The study's main constructs were subjected to the Shapiro-Wilk (SW) and Kolmogorov-Smirnov (KS) tests of normality and are presented in Table 3.

Table 3: Tests for normality

	Kolmogorov-Smirnov*			**Shapiro-Wilk**		
	Statistic	df	Sig.	Statistic	df	Sig.
Motivation Composite	0.112	133	0.000	0.952	133	0.000
LS Composite	0.095	133	0.005	0.980	133	0.045
SE Composite	0.069	133	0.200†	0.987	133	0.233

* Lilliefors significance correction
† this is the lower bound of the true significance

When it comes to normality testing, the null hypothesis states that the sampling distributions are *not* normal. As can be observed in Table 3 the constructs of Motivation and Learning Styles (LS) pass the test for normality (null hypothesis rejected, $p < 0.05$). However, the construct of Self-efficacy (SE) fails the test of normality (null hypothesis accepted, ($p > 0.05$) because the probability that the sampling distribution is not normal is quite high.

4.3 Conceptual Model and Empirical Findings

4.3.1 Motivation to Learn Computer Programming

The construct of Motivation (to learn computer programming) has been represented by 8 questionnaire items where 5 represent intrinsic motivation (IM) and 3 represent extrinsic motivation (EM). An overall presentation of the responses is provided in Figure 5.

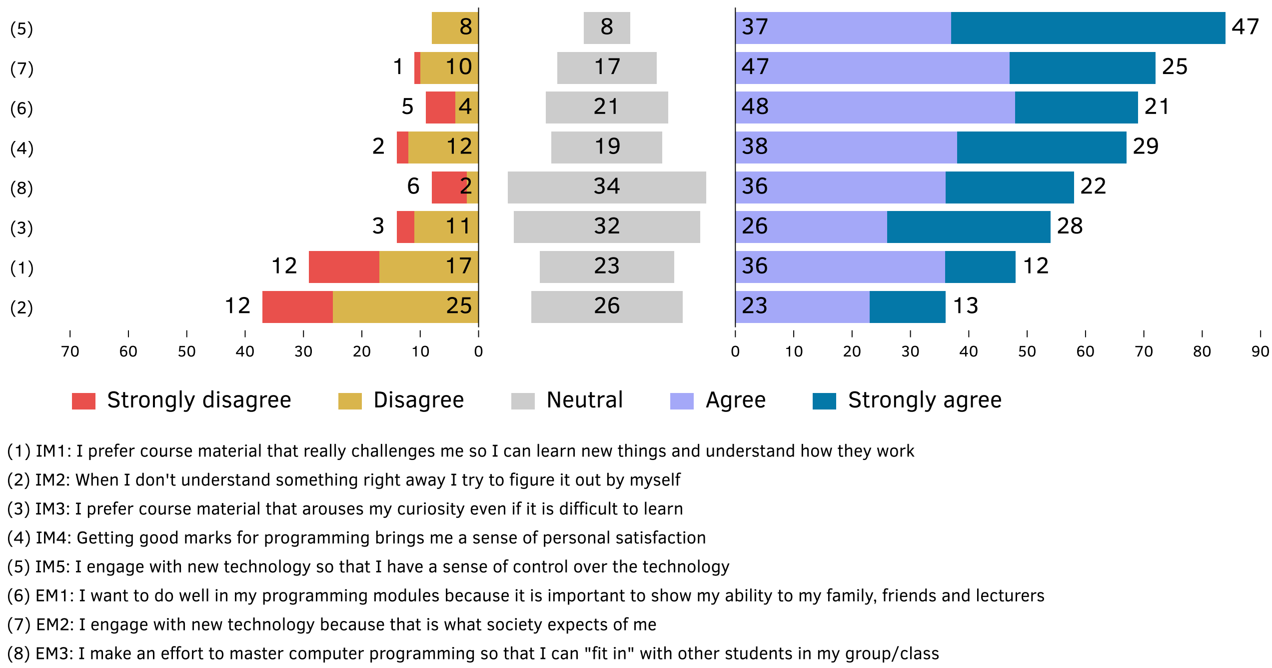

Figure 5: Overall view of responses for the construct of Motivation (sorted by positive responses)

Table 4: Measures of central tendency for Motivation

Motivation	N Valid	Missing	**Mean**	**Median**	**Mode**	**Standard Deviation**
IM1: I prefer course material that really challenges me so I can learn new things	133	0	3.67	4	4	1.029
IM2: When I don't understand something right away I try to figure it out by myself	133	0	3.87	4	4	0.900
IM3: I prefer course material that arouses my curiosity even if it is difficult to learn	133	0	3.77	4	4	1.000
IM4: Getting good marks for programming brings me a sense of personal satisfaction	133	0	4.23	4	5	0.900
IM5: I engage with new technology so that I have a sense of control over the technology	133	0	3.84	4	4	1.006
EM1: I want to do well in my programming modules because it is important to show my ability to my family, friends and lecturers	133	0	3.65	4	3	1.095
EM2: I engage with new technology because that is what society expects of me	133	0	3.02	3	3	1.225
EM3: I make an effort to master computer programming so that I can "fit in" with other students in my group/class	133	0	3.20	3	4	1.209

The measures of central tendency for the Motivation construct are displayed in Table 4.

As can be observed in Table 4, the mean response is in excess of 3 ($M > 3$) and the median is greater than or equal to 3 in all cases ($Mdn \geq 3$). To establish whether the mean and median values are significant measures of central tendency for the dataset shown in Table 4 or whether these values occur by chance, the one sample t-test is used. The one sample t-test may be used to determine if the mean of a sample is significantly different from a hypothesised value (DeCoster & Claypool, 2004). In the context of the current data (Table 4), the null hypothesis is that the mean (parametric) is equal to a hypothesised neutral value of 3 (H_0:M=3) and median (non-parametric) is equal to a hypothesised neutral value of 3 (H_0:$Mdn = 3$). In both cases, the alternate hypothesis is that these measures of central tendency are significantly different from 3 ($H_a \neq 3$). The t-test to establish the significance of the measures of central tendency has revealed results that are identical to the non-parametric equivalent test, which is the one-sampled Wilcoxon signed rank test illustrated in Table A1 in Appendix A.

As can be observed in Table A1 in Appendix A, the observed means were significantly greater than the hypothesised means of 3 in 6 of the 8 (75%) questionnaire items. Five of the 6 items were aligned to observable measures of IM. The implication from this analysis is that there is a significant ($p < 0.05$) tendency by the respondents to opt for responses that indicate high levels of IM to learn computer programming. This result indicates that the majority of the study's respondents have IM towards learning and mastering computer programming. A similar conclusion cannot be made when it comes to the EM factors; items 7 and 8 on the questionnaire did not yield a significant ($p > 0.05$) outcome, thereby reducing the prospect of a 95% confidence with conclusions made in terms of EM.

4.3.2 Learning Styles in Computer Programming

The construct of Learning Styles is represented by 6 questionnaire items where 3 of the items were positively worded in favour of a deep learning style and the remaining 3 items were positively worded in favour of a surface learning style. Essentially the learning style component represents students' deep or surface Learning Styles adopted for passing computer programming assessments. An overall presentation of the responses is provided in Figure 6.

The measures of central tendency for the Learning Styles construct are displayed in Table 5. As can be observed in Table 5, the mean response is in excess of 3 ($M > 3$) and the median is greater than or equal to 3 in all cases ($Mdn \geq 3$). To establish whether the mean and median values are significant measures of central tendency for the dataset shown in Table 5 or whether these values occur by chance, the one sample t-test was used. The results of the one sample t-test as well as the Wilcoxon Signed Rank test are shown in Table A2 in Appendix A.

As can be observed in Table A2 in Appendix A. the observed means were significantly greater than the hypothesised mean of 3 for 6 questionnaire items (100%). The implication from this analysis is that there is a significant ($p < 0.05$) tendency by the respondents to opt for responses that indicate high levels of deep learning. Another significant observation is that two of the questionnaire items that were positively worded to indicate surface learning were also significantly ($p < 0.05$) greater than the hypothesised mean of 3. While the responses

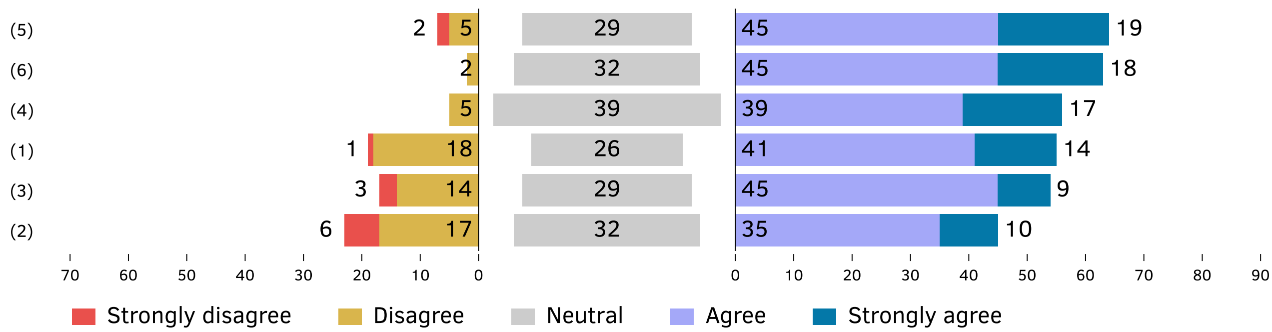

Figure 6: Overall view of responses for the construct of Learning Styles (sorted by positive responses)

Table 5: Measures of central tendency for Learning Styles

Learning Styles	N Valid	N Missing	Mean	Median	Mode	Standard Deviation
LS1: I find most new topics interesting and will often spend extra time trying to understand how they work	133	0	3.79	4	4	0.779
LS2: I find it helpful to study topics in depth rather than trying to remember important facts for tests	133	0	3.79	4	4	0.835
LS3: I test myself on important topics until I understand them completely	133	0	3.68	4	4	0.801
LS4: I tend to study best by using memorisation techniques	133	0	3.48	4	4	0.910
LS5: I find the best way to pass tests is trying to learn the answers to likely questions	133	0	3.29	3	4	1.013
LS6: I prefer to ensure that I pass a course even though my understanding of concepts may not be very good	133	0	3.47	4	4	0.989

pertaining to deep learning are indicative of the learning style used to master computer programming, the high scores reported for surface learning are indicative of an intention from the study's respondents to also ensure that they engage in techniques of learning that empower them with a maximum opportunity to pass the computer programming assessment activity.

4.3.3 Self-Efficacy in Computer Programming

The construct of Self-Efficacy (SE) is represented by 12 questionnaire items where 9 of the items were positively worded in favour of high levels of SE and 3 questionnaire items were positively worded in favour of low levels of SE. This construct consisted of questionnaire items that were directed at specific aspects of computer programming. These aspects consisted of: the ability to write procedural and object-oriented code (4 questionnaire items); the ability to debug and recover from errors and the ability to trace through the logic of computer programming code (2 questionnaire items); the ability to compile a logical computer programming solution to a given problem in a specified time range (4 questionnaire items); and the inclination to seek assistance when it comes to the writing of computer programming solutions (2 questionnaire items). An overall presentation of the responses is provided in Figure 7.

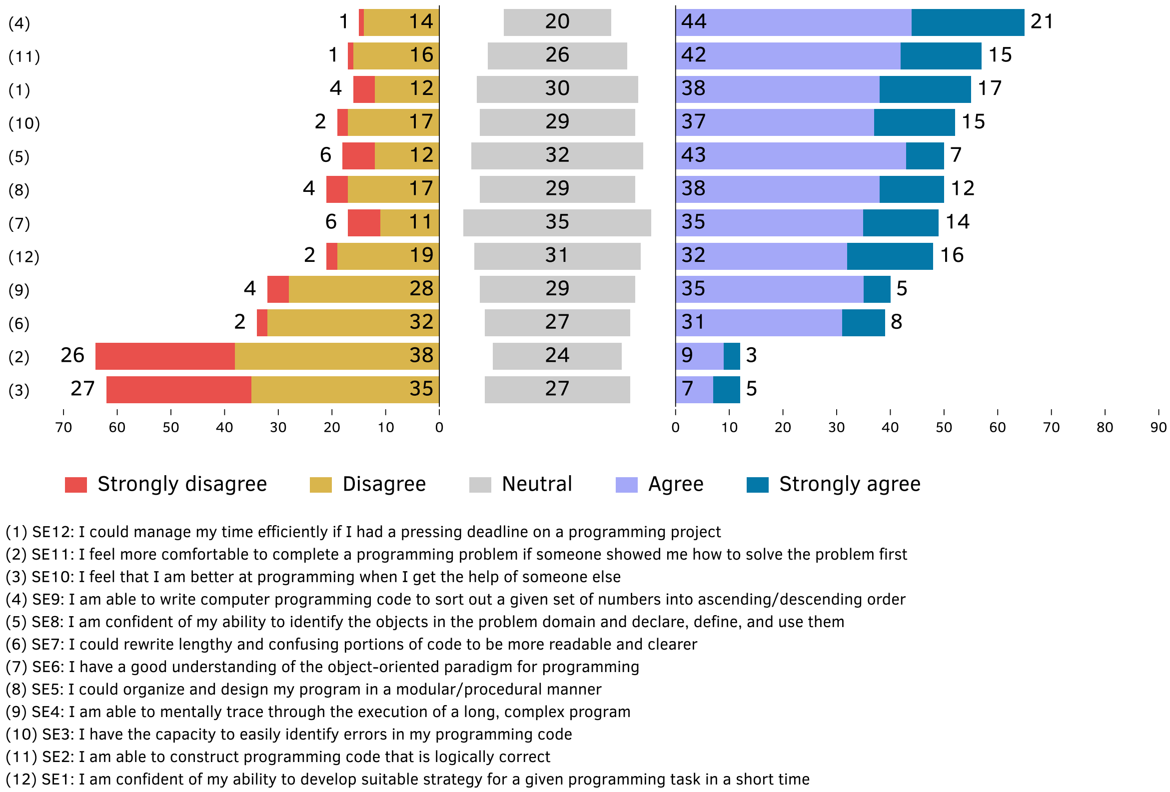

Figure 7: Overall view of responses for the construct of Self-Efficacy (sorted by positive responses)

The aggregated outcome of the frequency representation for the SE construct is shown in Table 6. As can be observed in Table 6, the mean response is in excess of 3 ($M > 3$) and the median is greater than or equal to 3 in 10 of the 12 cases ($Mdn \geq 3$). In 2 instances, the mean and median response is less than 3. It should be noted that in both of the cases where the mean and median were less than 3, the questionnaire items were phrased positively towards lower levels of SE. The one sample t-test was used to ascertain whether the measures of central tendency were significant or occurred by chance. The results of the one sample t-test as well as the Wilcoxon Signed Rank test are shown in Table A3 (in Appendix A).

From Table A3, it can be observed that there is a significant difference ($p < 0.05$) between the mean and median values for 10 of the 12 items. Questionnaire items 4 and 7 did not yield results that are significant ($p > 0.05$), meaning that there was no significant agreement

Table 6: Measures of central tendency for Self-Efficacy

Self-efficacy	N valid	N missing	Mean	Median	Mode	Standard deviation
SE1: I am confident of my ability to develop suitable strategy for a given programming task in a short time	133	0	3.41	3	4	1.037
SE2: I am able to construct programming code that is logically correct	133	0	3.55	4	4	0.957
SE3: I have the capacity to easily identify errors in my programming code	133	0	3.47	4	4	0.997
SE4: I am able to mentally trace through the execution of a long, complex program	133	0	3.09	3	4	0.981
SE5: I could organize and design my program in a modular/procedural manner	133	0	3.37	3	4	1.026
SE6: I have a good understanding of the object-oriented paradigm for programming	133	0	3.39	3	3	1.043
SE6: I have a good understanding of the object-oriented paradigm for programming	133	0	3.09	3	2	1.011
SE8: I am confident of my ability to identify the objects in the problem domain and declare, define, and use them	133	0	3.32	3	4	0.981
SE9: I am able to write computer programming code to sort out a given set of numbers into ascending/descending order	133	0	3.70	4	4	0.985
SE10: I feel that I am better at programming when I get the help of someone else	133	0	2.27	2	2	1.074
SE11: I feel more comfortable to complete a programming problem if someone showed me how to solve the problem first	133	0	2.25	2	2	1.040
SE12: I could manage my time efficiently if I had a pressing deadline on a programming project	133	0	3.51	4	4	1.027

on the ability to mentally trace through the execution of a long and complex program and to rewrite lengthy and complex portions of code to make them more readable and clearer. This demonstrates that the respondents' self-efficacy did not extend to these two competencies. The questionnaire items that were positively worded in favour of high levels of SE showed a significant positive difference from the hypothesised neutral values for the mean and median. This outcome is indicative of a high level of SE being displayed by the respondents of the study towards the handling of computer programming tasks. The preceding outcome is further corroborated by the negative differences recorded for questionnaire items 10 and 11. These questionnaire items were positively worded to indicate low levels of SE. The low means and medians recorded are an indication that the respondents disagreed with the statements attesting to low levels of SE when it comes to academic performance in computer programming.

4.3.4 Problem-Solving Ability and Performance in Computer Programming

The construct of Problem-Solving Ability was operationalised/measured by adapting the computer programming aptitude test used by Tukiainen and Mönkkönen (2002) in predicting computer programming competence. The test to measure computer programming competence was presented to the study's respondents as a series of problem-solving tasks that tested their cognitive processing ability when faced with computer programming related questions. These tasks were adapted to align with the computer programming content that was delivered to the respondents of the current study during their tenure as students following the IS&T curriculum at UKZN. The classification of questionnaire items used for the Problem-Solving Ability construct is presented in Table 7.

Table 7: Classification of questionnaire items for Problem-Solving Ability

Computer programming concept	**Number of questionnaire items**
Conditional Logic (Logical Operators)	2
Predictive Logic	3
Comparative Logic	1
Iterative Logic	2
Assignment Logic	1
Data Structure Logic	1

Respondents of the study were presented with the set of 10 computer programming related tasks listed in Table 7 and were required to provide a response that was structured as a multiple-choice type of question. Each of the study's respondents were scored on their performance by allocating a point value of 1 for a correct answer and 0 for an incorrect answer.

In this way, each respondent scored a mark out of 10, thereby providing a quantified indicator of the Problem-Solving Ability of the student.

The study's respondents were also required to provide an approximate measure of their academic performance in computer programming assessment. These values were recorded using a scale of 1 to 8. A bivariate correlation analysis was conducted between the respondents' academic performance and their Problem-Solving Ability. The results are presented in Table 8.

As can be seen in Table 8, the Pearson product-moment correlation coefficient (PPMCC) is statistically significant ($r = 0.59$, $N = 133$, $p < 0.01$, two-tailed). The interpretation from this result is that there is a significantly positive relationship between the respondents' academic performance in computer programming assessment and their Problem-Solving Ability in the context of computer programming tasks. This result provides a measure of validity to the construct of academic performance score, which is an estimated value provided by the study's respondents.

4.4 Reliability Testing

For the current study, three constructs were measured using a Likert-scale type of response. The outcome of the Cronbach alpha reliability tests that were conducted on these constructs are presented in Table 9.

https://doi.org/10.18489/sacj.v36i1.18819

Table 8: Academic performance in Computer Programming vs Problem-Solving Ability

		Problem-Solving Ability	Computer Programming Performance (numeric)
Problem-Solving Ability	Pearson Correlation	1	0.588*
	Sigma (2-tailed)		0.000
	N	133	133
Computer Programming Performance (numeric)	Pearson Correlation	0.588*	1
	Sigma (2-tailed)	0.000	
	N	133	133

* correlation is significant at the 0.01 level (2-tailed)

Table 9: Cronbach Alpha analysis

Construct	No of Likert Scale Items	Cronbach's alpha
Motivation (intrinsic and extrinsic)	8 (IM1 to IM5, EM1 to EM3)	0.64
Learning Styles	6 (LS1 to LS6)	0.57
Self-Efficacy	12 (SE1 to SE12)	0.91

Cronbach alpha co-efficient values in the range of 0.7 and above are considered to be good reliability estimates (Sekaran & Bougie, 2016). In Table 9, it can be observed that the Cronbach alpha value for Learning Styles is 0.57 and that of Motivation is 0.64, from which it is inferred that the questionnaire items used to measure these two constructs are not ideally reliable. The constructs were subjected to further validity testing in the form of factor analysis. This is described in the next section.

4.5 Confirmatory Factor Analysis

The process of variable reduction is conducted under the theory that, if the conceptual model does not have an alignment with the study's data, then the conceptual model needs to be rearranged so that it has an optimal alignment with the study's data. This process of fitting the conceptual model to the study's data is referred to as confirmatory factor analysis (CFA), which is a crucial process in ensuring construct validity (Pham et al., 2020).

Three questionnaire items for Motivation and three questionnaire items for Learning Styles identified as significant contributors to the "poor" Cronbach Alpha values in Table 9 were removed from further analysis. In addition, to improve the model fit of the study's conceptual model, the modification indices were examined during CFA and three items that showed high levels of covariance with other items from the SE construct were removed. From an item reliability perspective, the improvement in the internal consistency of the empirical model is confirmed by the reworked Cronbach alpha values shown in Table 10.

Table 10: Re-worked Cronbach Alpha analysis

Construct	No of Likert Scale Items	Cronbach's alpha
Motivation (intrinsic and extrinsic)	5 (IM1 to IM5)	0.83
Learning Styles	3 (LS1 to LS3)	0.72
Self-Efficacy	9 (SE1 to SE9)	0.93

In Figure 8, the ellipses labelled e4 to e8; e12 to e14 and e15 to e23 refer to the labels of the arrow dumps. The boxes labelled IM1 to IM5, LS1 to LS3 and SE1 to SE9 represent the measured variables. The circles labelled Motivation, Learning Style and Self-Efficacy represent the latent variables, called factors. The item weights in the arrows between the latent variables and the measured variables represents the factor loadings. The double headed arrows between the latent variables Motivation, Learning Style and Self-Efficacy represent correlations

In the context of the current study, the "model fit" indicators arising out of Figure 8 are Comparative Fit Index (CFI) = 0.91, the Tucker Lewis Index (TLI) = 0.9 and the root mean square error of approximation (RMSEA) = 0.082. The measurements for an acceptable model fit are as follows: The CFI index measurement should be closer to 1; the TLI should be in the range of 0,9 to 1; and the RMSEA should be less than 0.08. A RMSEA value that is less than 0.08 and a CFI value of 0.9 or greater are indicators of a good model fit. These results indicate that the empirical model that will be used for the data analysis for the study is not a perfect fit to the study's data but it is closely aligned with the suggested test statistics to ensure a "good fitting" model.

4.6 Correlation Analysis

The main aim of the study was to establish the validity of correlations between the study's main variables as well as the study's conceptual model, illustrated in Figure 1. The course of the correlation analysis is guided by the study by Musil et al. (1998).

4.6.1 Bivariate Correlation Analysis

The data representing the study's main constructs is represented by ordinal scales and the PPMCC may be used to determine the relationship between these constructs (Spada & Moneta, 2012). The Pearson correlation analysis was chosen to establish the significance of relationships between the study's main constructs. It was decided to use the questionnaire items that were positively worded to ascertain levels of deep learning regarding the attainment of good academic performance in computer programming for the generation of the bivariate

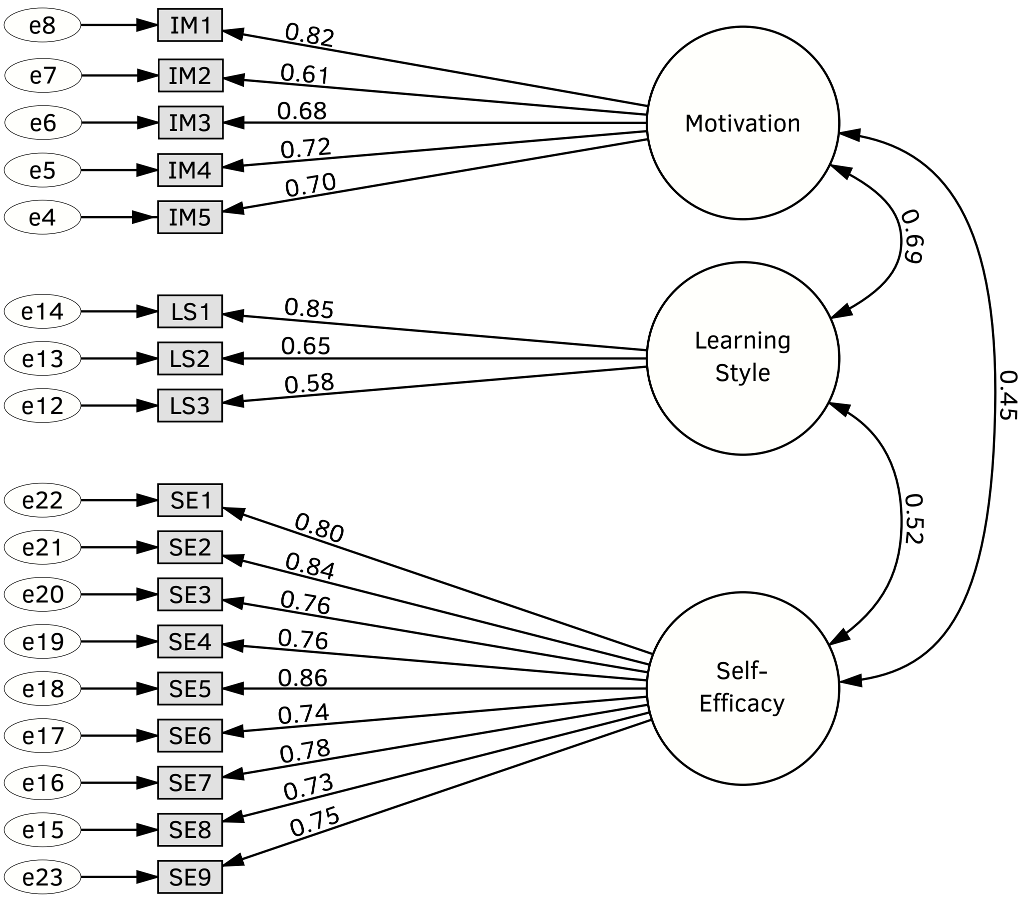

Figure 8: Confirmatory Factor Analysis of the Observed Values

correlation matrix shown in Table 11. From Table 11, the following statistically significant correlations can be observed:

- There exists a moderate positive correlation between Problem-Solving Ability and Computer Programming Performance ($r = 0.59$, $N = 133$, $p < 0.01$, two-tailed)
- There exists a moderate positive correlation between Problem-Solving Ability and Computer Programming Experience ($r = 0.55$ $N = 133$, $p < 0.01$, two-tailed)
- There exists a weak positive correlation between Problem-Solving Ability and Learning Styles (deep learning) ($r = 0.20$ $N = 133$, $p < 0.05$, two-tailed)
- There exists a moderate positive correlation between Problem-Solving Ability and Self-Efficacy ($r = 0.43$, $N = 133$, $p < 0.01$, two-tailed)
- There exists a moderate positive correlation between Programming Experience and Computer Programming Performance ($r = 0.51$, $N = 133$, $p < 0.01$, two-tailed)

- There exists a weak positive correlation between Programming Experience and Learning Styles (deep learning) ($r = 0.23$ $N = 133$, $p < 0.01$, two-tailed)
- There exists a moderate positive correlation between Programming Experience and Self-Efficacy ($r = 0.51$ $N = 133$, $p < 0.01$, two-tailed)
- There exists a weak positive correlation between Learning Styles (deep learning) and Computer Programming Performance ($r = 0.21$ $N = 133$, $p < 0.05$, two-tailed)
- There exists a moderate positive correlation between Learning Styles (deep learning) and Self-Efficacy ($r = 0.42$ $N = 133$, $p < 0.01$, two-tailed)
- There exists a moderate positive correlation between Self-Efficacy and Computer Programming Performance ($r = 0.57$, $N = 133$, $p < 0.01$, two-tailed)
- There exists a moderate positive correlation between Motivation and Learning Styles (deep learning) ($r = 0.51$, $N = 133$, $p < 0.01$, two-tailed)
- There exists a weak positive correlation between Motivation and Self-Efficacy ($r = 0.20$ $N = 133$, $p < 0.05$, two-tailed)

The results in Table 11 indicate that the bivariate correlations between Motivation and Problem-Solving Ability; Motivation and Computer Programming Performance; Motivation and Programming Experience are not significant.

The results from the current study are consistent with those observed in the systematic literature review by Medeiros et al. (2019), who found that in a majority of studies, there is evidence of a positive relationship between programming experience and proficiency in computer programming. The result of the correlation between Self-Efficacy and Computer Programming Performance was supported in a study by I. Govender et al. (2014) where a strong link was established between SE in Problem-Solving Ability and SE in Computer Programming. The correlation between Problem-Solving Ability and Computer Programming Performance is supported by Lishinski et al. (2016), who indicated that Problem-Solving Ability is significantly correlated with good academic performance on programming assignments. The correlation between Problem-Solving Ability and Learning Styles is supported by Malik et al. (2019), who argue that teaching problem-solving skills will inherently promote deep learning techniques among students.

4.6.2 Multiple Regression Analysis (MRA)

The next step after bivariate correlations is to examine the combined effect of multiple independent variables with the dependent variable (Swanson & Holton, 2005). The objective of multiple regression is to provide the researcher with empirical evidence for making decisions regarding the predictive capacity of the study's conceptual model or for enabling an explanation of the relationship between the independent and dependent variables in the study. In

Table 11: Bivariate correlation of the study's main constructs

		Problem-Solving Ability	Computer Programming Performance (numeric)	Programming Experience	Learning Style Deep	Self-Efficacy	Motivation
Problem-Solving Ability	N	133	133	133	133	133	133
	Pearson Correlation	1	0.588*	0.553*	0.202†	0.434*	0.002
	Sigma (2-tailed)		0.000	0.000	0.020	0.000	0.986
Computer Programming Performance (numeric)	Pearson Correlation	0.588*	1	0.506*	0.214†	0.572*	0.130
	Sigma (2-tailed)	0.000		0.000	0.014	0.000	0.137
Programming Experience	Pearson Correlation	0.553*	0.506*	1	0.235*	0.512*	0.131
	Sigma (2-tailed)	0.000	0.000		0.006	0.000	0.134
Learning Style Deep	Pearson Correlation	0.202†	0.214†	0.235*	1	0.421*	0.505*
	Sigma (2-tailed)	0.020	0.014	0.006		0.000	0.000
Self-Efficacy	Pearson Correlation	0.434*	0.572*	0.512*	0.421*	1	0.202†
	Sigma (2-tailed)	0.000	0.000	0.000	0.000		0.020
Motivation	Pearson Correlation	0.002	0.130	0.131	0.505*	0.202†	1
	Sigma (2-tailed)	0.986	0.137	0.134	0.000	0.020	

* correlation is significant at the 0.01 level (2-tailed)
† correlation is significant at the 0.05 level (2-tailed)

the context of the data for the current study, the multiple regression model is guided by Pham et al. (2020). The first output from this analysis is the Model Summary output, shown in Table 12. The analysis of variance (ANOVA) output is shown in Table 13.

Table 12: Model summary for MRA

Model	R	R^2	Adjusted R^2	Std error of estimate
1	0.697*	0.485	0.465	0.817

* Predictors: (Constant), MotivationCompositeMean, Problem-Solving Ability, SECompositeMean, LS_Deep, ProgExperience

By analysing Tables 12 and 13, it can be established that the combined independent variables significantly predict Computer Programming Performance. The statistics that support

Table 13: ANOVA* showing the significance of the model

Model		Sum of squares	df	Mean²	F	Significance
1	Regression	79.976	5	15.995	23.966	<0.001 †
	Residual	84.761	127	0.667		
	Total	164.737	132			

* Dependent Variable: Computer Programming Performance (numeric)
† Predictors: (Constant), MotivationCompositeMean, Problem-Solving Ability, SECompositeMean, LS_Deep, ProgExperience

this conclusion are listed below:

- The F-statistic in Table 13 ($F(5) = 23.96$ ($p < 0.01$)) is an indicator of the significance of the study's multiple regression model.
- The F-statistic provides a validation indicator for the conclusion that the composite set of independent variables explains 46.5% of the variance in the dependent variable ($R = 0.7$; $R^2 = 0.485$; adjusted $R^2 = 0.465$; $p < 0.01$) as indicated in Table 12.

The final multiple regression output is to examine the coefficient values listed in Table 14, where it can be seen from the Beta values that Problem-Solving Ability and SE are the two main predictors of Computer Programming Performance ($p < 0.01$). The findings on SE concurs with the study conducted by I. Govender et al. (2014), where a strong link was established between SE in problem solving and SE in computer programming. The current study extends the network of influence regarding SE by showing a moderate, positive correlation between SE and a deep learning style. The current study also shows a moderate positive correlation between SE and Programming Experience, which is supported by Kolar et al. (2013). Problem-Solving Ability shows a moderate positive correlation with Computer Programming Performance. This outcome is confirmed in the report compiled by Medeiros et al. (2019), where 26 papers on this topic were reviewed, as well as findings reported by Mahatanankoon and Wolf (2021), and Lonka et al. (2004).

It should also be noted that, according to the data presented in Table 14, Programming Experience, Learning Styles and Motivation are not significant predictors of Computer Programming Performance. This finding was supported by Bennedsen et al. (2007), who found that students with programming experience did not outperform students who did not have programming computer programming experience as they relied heavily on their past knowledge and fell behind with the course material. The finding on deep Learning Styles being a peripheral influence on computer programming achievement may be attributed to the fact that students need to embrace both surface and deep learning styles because of the skill-based nature of programming (Lindblom-Ylänne et al., 2019), as well as the finding that 50% of computer programming students at higher education institutions tend to adopt a surface learning style for introductory computer programming courses (Ranjeeth, 2011).

Table 14: Coefficients of the Multiple Regression Model* showing the significance of the model

Model		Unstandardised Coefficients		Standardised Coefficients		
		B	Std. error	Beta	t	Sig.
1	(constant)	0.974	0.513		1.897	0.060
	ProgExperience	0.132	0.093	0.117	1.418	0.159
	Problem-Solving Ability	0.022	0.004	0.382	4.837	0.000
	SECompositeMean	0.577	0.128	0.366	4.524	0.000
	LS_Deep	-0.152	0.139	-0.088	-1.100	0.273
	MotivationCompositeMean	0.148	0.131	0.084	1.130	0.261

* Dependent Variable: Computer Programming Performance (numeric)

The construct of Motivation played a minimal role in predicting Computer Programming Performance. This outcome is contrary to the results reported by Bergin and Reilly (2005), who found that IM and EM were strongly aligned to Computer Programming Performance. The finding on Motivation not being a significant predictor of Computer Programming Performance can be attributed to the fact that Motivation can be negatively affected by the need to do challenging programming exercises and to expend a great deal of effort in grasping programming concepts (Durak et al., 2019).

5 CONCLUSION AND RECOMMENDATIONS

This study was aimed at addressing the issue of students struggling to obtain proficiency in the domain of computer programming. There have been numerous studies previously that have studied this phenomenon and knowledge around this topic has grown substantially. The problem of poor performance in computer programming does, however, continue to exist. The current study was grounded in the previous efforts to find a solution to this phenomenon. The difference, however, is that this study adopted a multidimensional approach by integrating five significant constructs into a single conceptual model, examining the role of each construct in relation to academic performance in computer programming. This study also showed the relative importance of each factor in contributing towards an improvement in students' performance in computer programming.

The study's findings relating to the main research question, "What are the factors that influence proficiency in computer programming at the higher education level?", are as follows:

Programming Experience and Computer Programming The bivariate correlation shows a moderate but significant, positive correlation with Computer Programming Performance.

This outcome suggests that Programming Experience does influence academic performance in computer programming. The knowledge obtained from the current study regarding Programming Experience is crucial because the implication is that, when Programming Experience is considered as part of a broader understanding of the factors that influence Computer Programming Performance, its significance is minimal as indicated in the Multiple Regression Model in Table 14.

Problem-Solving Ability and Computer Programming The bivariate correlational analysis shows that Problem-Solving Ability has a moderate, significant positive correlation with Computer Programming Performance. The multiple regression analysis indicates that Problem-Solving Ability is a main predictor of Computer Programming Performance. The implication from these results suggest that universities need to invest more time at 1st-year level with a focus on logical reasoning and algorithmic thinking so that students can obtain foundation knowledge on computer programming semantic structures to enhance problem solving. This observation has significant implications for students who have not had prior experience in computer programming because a focus on algorithmic thinking would equip them with the cognitive structures required to obtain a deep understanding of computer programming logic.

Self-Efficacy (SE) and Computer Programming The bivariate correlational analysis shows there is a moderate but significant, positive correlation between SE and Computer Programming Performance. The multiple regression analysis indicates that SE is a main predictor of Computer Programming Performance. The current study also confirms a moderate, significant positive correlation between SE and Programming Experience. The current study extends the network of influence regarding SE by observing that there is a moderate, significant positive correlation between SE and a deep learning style. These observations are significant from a pedagogical perspective because educators should make a concerted effort to enhance and enable high levels of SE amongst students in their programming courses.

Motivation and Computer Programming The construct of Motivation played a minimal role in predicting Computer Programming Performance. While this construct had a weak but positive correlation with SE and a moderate positive correlation with Learning Styles, it did not display a significant relationship with Problem-Solving Ability, Programming Experience or Computer Programming Performance.

Learning styles and Computer Programming The study shows that a weak positive correlation exists between Problem-Solving Ability and Learning Styles (deep learning) but contributes to Computer Programming Performance only peripherally.

The Model Summary output and the analysis of variance (ANOVA) output in Tables 12 and 13 demonstrated that the combined independent variables (Motivation, Problem-Solving

Ability, Self-Efficacy, Programming Experience and Learning Styles) significantly predict Computer Programming Performance.

The main limitation of the study is the threat to external validity because a larger, more expansive sample would have created an opportunity for greater generalisation of the study's results. The delimitation of confining the study to IS&T students was necessitated by the researcher's concerns when it came to data collection because, at the commencement of the study, the COVID-19 pandemic prevented free and open communication with potential respondents. The researcher's field study was confined to IS&T platforms that were made available online. Another limitation of the study was the potential breach of internal validity because the measurement of student programming performance was done through estimates provided by the study respondents. This potential weakness in the study was, however, mitigated by the inclusion of problem-solving tasks in the study's questionnaire. The strong positive correlation between the scores obtained in the problem- solving tasks and the respondents' estimation of their performance in computer programming assessment enhanced the reliability of these variables.

The findings contribute to the body of knowledge in computer programming pedagogy, which could lead to improved student performance in assessment tasks, as well as to validating the adopted conceptual model. The findings emphasise the role played by Self-Efficacy as a significant predictor of Computer Programming Performance as well as its significant, positive correlations with the four major factors, namely Problem-Solving Ability, Programming Experience, Learning Styles (deep learning) and Motivation. The finding on Problem-Solving Ability as a significant predictor of Computer Programming Performance contributes to the wider argument on the effects of problem solving on computer programming performance and vice versa and its potential to improve cognitive skills such as creative thinking, mathematical skills, and reasoning, thereby promoting computational thinking skills in education and society. The findings of the adopted conceptual model demonstrate the importance of the many factors that have direct or indirect effects on student performance in computer programming courses, including Problem-Solving Ability, Self-Efficacy, Programming Experience, Motivation and Learning Styles. The findings of the study have implications for educational practice as the personalized learning instructional approach and multiple learning opportunities can be used to improve individual student performance in computer programming.

A further outcome of the study is the development and validation of a conceptual model to predict Computer Programming Performance. This model has been subjected to validity testing in the form of confirmatory factor analysis and multiple regression analysis. It is recommended that future studies explore the role that Motivation and Learning Styles play when students learn programming in an online distance learning environment as opposed to a face-to-face setting or a hybrid learning environment.

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A STATISTICAL TESTS

Table A1: One-sampled Wilcoxon signed rank test for Motivation

	1-sample t-test Test value = 3					1-sample Wilcoxon signed rank test	
			Significance				
Motivation	**t**	**df**	1-sided p	2-sided p	**Mean difference**	**Sig.***†	**Decision** Null hypothesis
IM1: I prefer course material that really challenges me so I can learn new things	7.508	132	0.000	0.000	0.669	0.000	Reject
IM2: When I don't understand something right away I try to figure it out by myself	11.181	132	0.000	0.000	0.872	0.000	Reject
IM3: I prefer course material that arouses my curiosity even if it is difficult to learn	8.852	132	0.000	0.000	0.767	0.000	Reject
IM4: Getting good marks for programming brings me a sense of personal satisfaction	15.681	132	0.000	0.000	1.226	0.000	Reject
IM5: I engage with new technology so that I have a sense of control over the technology	9.650	132	0.000	0.000	0.842	0.000	Reject
EM1: I want to do well in my programming modules because it is important to show my ability to my family, friends and lecturers	6.808	132	0.000	0.000	0.647	0.000	Reject
EM2: I engage with new technology because that is what society expects of me	0.142	132	0.444	0.888	0.015	0.880	Retain
EM3: I make an effort to master computer programming so that I can "fit in" with other students in my group/class	1.865	132	0.032	0.064	0.195	0.107	Retain

* The significance level is .050
† Asymptotic significance is displayed

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Table A2: One-sampled Wilcoxon signed rank test for Learning Styles

	1-sample t-test Test value = 3					**1-sample Wilcoxon signed rank test**	
			Significance				
Learning Styles	**t**	**df**	1-sided p	2-sided p	**Mean difference**	**Sig.**[*†]	**Decision** Null hypothesis
LS1: I find most new topics interesting and will often spend extra time trying to understand how they work	11.687	132	0.000	0.000	0.789	0.000	Reject
LS2: I find it helpful to study topics in depth rather than trying to remember important facts for tests	10.900	132	0.000	0.000	0.789	0.000	Reject
LS3: I test myself on important topics until I understand them completely	9.848	132	0.000	0.000	0.684	0.000	Reject
LS4: I tend to study best by using memorisation techniques	6.101	132	0.000	0.000	0.481	0.000	Reject
LS5: I find the best way to pass tests is trying to learn the answers to likely questions	3.337	132	0.001	0.001	0.293	0.002	Reject
LS6: I prefer to ensure that I pass a course even though my understanding of concepts may not be very good	5.523	132	0.000	0.000	0.474	0.000	Reject

[*] The significance level is .050
[†] Asymptotic significance is displayed

Table A3: Significance testing for Self-Efficacy

Self-efficacy	1-sample t-test Test value = 3 t	df	Significance 1-sided p	Significance 2-sided p	Mean difference	1-sample Wilcoxon signed rank test Sig.*†	Decision Null hypothesis
SE1: I am confident of my ability to develop suitable strategy for a given programming task in a short time	4.513	132	0.000	0.000	0.406	0.000	Reject
SE2: I am able to construct programming code that is logically correct	6.613	132	0.000	0.000	0.549	0.000	Reject
SE3: I have the capacity to easily identify errors in my programming code	5.480	132	0.000	0.000	0.474	0.000	Reject
SE4: I am able to mentally trace through the execution of a long, complex program	1.061	132	0.145	0.291	0.090	0.294	Retain
SE5: I could organize and design my program in a modular/procedural manner	4.141	132	0.000	0.000	0.368	0.000	Reject
SE6: I have a good understanding of the object-oriented paradigm for programming	4.322	132	0.000	0.000	0.391	0.000	Reject
SE7: I could rewrite lengthy and confusing portions of code to be more readable and clearer	1.029	132	0.153	0.305	0.090	0.278	Retain
SE8: I am confident of my ability to identify the objects in the problem domain and declare, define, and use them	3.800	132	0.000	0.000	0.323	0.001	Reject
SE9: I am able to write computer programming code to sort out a given set of numbers into ascending/descending order	8.190	132	0.000	0.000	0.699	0.000	Reject
SE10: I feel that I am better at programming when I get the help of someone else	-7.832	132	0.000	0.000	-0.729	0.000	Reject
SE11: I feel more comfortable to complete a programming problem if someone showed me how to solve the problem first	-8.336	132	0.000	0.000	-0.752	0.000	Reject
SE12: I could manage my time efficiently if I had a pressing deadline on a programming project	5.741	132	0.000	0.000	0.511	0.000	Reject

* The significance level is .050
† Asymptotic significance is displayed

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Research Article

Towards Human-AI Symbiosis: Designing an Artificial Intelligence Adoption Framework

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ABSTRACT
Organisations need to adopt AI successfully and responsibly. AI's technical capabilities make AI powerful. However, the implementation of AI in organisations is not limited to the technical elements and requires a more holistic approach. An AI implementation within an organisation is a sociotechnical system, with the interplay between social and technical components. Considering the sociotechnical nature of AI in organisations, the following research question arises: *From a sociotechnical perspective, how can an organisation increase adoption of AI as part of its quest to become more data-driven?* In light of the research question, we propose to create a sociotechnical artificial intelligence adoption framework with a target audience of both academics and practitioners. This study follows a design science research approach, constituting various iterative cycles. The study is conducted at an automotive manufacturer's IT Hub based in South Africa and has the aim to gain concrete, contextual, in-depth knowledge about a specific real-world organisation. To achieve this, focus groups serve as the primary research method. As the organisation at which the study took place is seen as a global leader in industrial digital transformation, the experience can help researchers and other organisations understand how an organisation can increase the adoption of AI.

Keywords Adoption, Organisation, Sociotechnical, Design Science Research, Artificial Intelligence

Categories • **Information systems** ~ **Information systems applications** • *Computing methodologies* ~ *Artificial intelligence*

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1 INTRODUCTION

Data-driven organisations are entities that act on observed data rather than merely gut feeling and do so to achieve financial or non-financial benefits (C. Anderson, 2015). It is commonly understood that the effective use of artificial intelligence (AI) as part of an organisation's analytics portfolio, is the most advanced level of data-drivenness (Berente et al., 2021; Davenport & Harris, 2007; Gupta & George, 2016). Organisations often struggle to reach this higher level of data-drivenness (Krishnamoorthi & Mathew, 2018; Schlegel et al., 2018). Failing to do so will cause organisations to lose out on opportunities that enable faster and largescale evidence-based decision-making (Manyika et al., 2017).

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When adopting AI as part of an organisation's analytics portfolio, organisations face multiple challenges, such as addressing the skill shortages and understanding how to use and reap AI's benefits (Reis et al., 2020). Realising the benefits of utilising AI (to support decision-making whilst having the required skills) but without the available technology platforms will hinder adoption success (IBM, 2022). This problem forms part of what is referred to as the knowledge-attitude-practice gap (KAP-gap) (Rogers, 1995). Furthermore, even when organisations adopt AI, they fall short of moving from proof of concepts to implementing AI in production environments (Benbya & Davenport, 2020). Additionally, advanced levels of data-drivenness with the support of AI, enable organisations to automate decision making (C. Anderson, 2015; Benbya & Davenport, 2020). When automated decisions have an impact on people, important legal and ethical considerations arise (Crawford, 2021). Researchers and organisations should acknowledge the importance of responsible AI adoption and ensure that the future impact of AI is beneficial (Russell et al., 2015). Therefore, the adoption of AI in organisations should not be limited to social or technical aspects, but should rather be a sociotechnical approach, focusing on the interplay between social and technical components of the systems within a complex environment (Wihlborg & Söderholm, 2013).

Given the requirements for organisations to solve the KAP-gap and to successfully adopt AI, considering the sociotechnical nature of AI in organisations, the following research question arises: *From a sociotechnical perspective, how can an organisation increase adoption of AI as part of its quest to become more data-driven?* In this paper, the successful use of AI as part of an organisation's analytics portfolio is called organisational AI adoption. In light of the research question, we propose creating a sociotechnical artificial intelligence adoption framework (AIAF) with a target audience of academics and practitioners.

This study directly extends the socio-specific artificial intelligence adoption framework presented at SAICSIT 2022 (Smit & Eybers, 2022). It follows a design science research (DSR) approach, constituting various iterative cycles. This study adds the technical aspects to the adoption framework (Smit, Eybers & van der Merwe, 2023), therefore making it a holistic sociotechnical AIAF. It is conducted at an automotive manufacturer's IT Hub[1] based in South Africa and aims to gain concrete, contextual, in-depth knowledge about a specific real-world organisation. As the organisation where the study took place is seen as a global leader in industrial digital transformation (ARC Advisory Group, 2022), the experience can help researchers and other organisations understand how an organisation can increase the adoption of AI as part of its quest to become more data-driven.

The remainder of the paper is structured as follows: Section 2 discusses related research, Section 3 explains the research approach, followed by Section 4, which covers the DSR cycle and artifact development and discussion. Section 5 discusses the results and is followed by the conclusion in Section 6.

[1] More detail on the IT Hub can be found on the website: https://www.bmwithub.co.za/.

2 LITERATURE REVIEW

Big data analytics provides organisations different opportunities to achieve new levels of competitive advantage (H. Chen et al., 2017). In the case of adopting AI as part of an organisation's big data analytics portfolio, AI enables cognitive automation within organisations (M. Lacity et al., 2021). Simulating intelligence is made possible through AI's ability to learn from data and perform certain tasks autonomously (Benbya & Davenport, 2020). By becoming data-driven, organisations better understand their costs, sales potential and emerging opportunities (Johnson et al., 2019). However, organisations struggle to adopt AI successfully (Schlegel et al., 2018) and the use of AI in organisations is still relatively new. To minimise disappointments, early adopters should expect and manage technical challenges (M. C. Lacity & Willcocks, 2021), such as challenges related to data collection, model training, and deployment (Luckow et al., 2018). Furthermore, stakeholders should take cognisance of possible adoption barriers such as limited AI skills, expertise or knowledge, the lack of tools or platforms to develop models, and the projects' complexity (IBM, 2022). Additionally, considering the potential negative impact of adopting AI is part of the duties of being a responsible organisation (Crawford, 2021).

2.1 Technology Adoption Theory

Fortunately, several theoretical frameworks on technology adoption could assist organisations with the adoption challenges of AI. For example, the theory of planned behaviour (TPB) (Taylor & Todd, 1995), the theory of reasoned action (TRA) (Fishbein & Ajzen, 1977), the technology acceptance model (TAM) (Davis et al., 1989), and the technological-organisational-environmental (TOE) framework are theories that assist in the understanding of technology adoption. Whilst the TOE framework focuses on organisational-level technology adoption (Tornatzky & Fleischer, 1990), the TPB, TRA and TAM are focused on the individual user's adoption of technologies. As the implementation of AI in organisations will impact humans and possibly the environment (and even though AI's technical capabilities are at the core of what AI offers), it is not limited to the technical elements and requires a more holistic approach (Crawford, 2021). The TOE framework includes the technological, organisational and environmental considerations, and as a result is useful as a holistic theoretical lens to study technology adoption in organisations (Tornatzky & Fleischer, 1990). Although being a traditional adoption framework, the TOE framework is appropriate as it adopts a holistic approach from an organisational perspective and allows for individual technology characteristics (Dwivedi et al., 2012).

In the context of the TOE framework, the technology refers to all the relevant technologies to the organisation. Some technological context-predicting factors significant to adoption are: compatibility, complexity (Grover, 1993), perceived barriers (Chau & Tam, 1997), technology integration (Zhu, Kraemer & Gurbaxani, 2006) and trialability (Ramdani et al., 2009). The technology innovations that create incremental change necessitate the smallest learning requirements. However, technological innovations that produce a discontinuous change (such as AI) require a substantial learning requirement and therefore have a substantial and dramatic impact on the organisation (Tushman & Nadler, 1986). An organisational context is the resources and characteristics of the organisation, including the firm size, structures between employees, intra-firm communication processes and the resource availability level (Dwivedi et al., 2012). The organisational structure and management leadership style also impact innovation adoption processes (Dwivedi et al., 2012). Additionally, within the organisational context, the scope extends beyond the organisational components to encompass the individual (Widyasari et al., 2018). The environmental context is the milieu in which the organisation exists and includes aspects such as the industry's structure, the service providers, the regulatory environment (Dwivedi et al., 2012), competitor pressures, customer pressures, partner pressures and government pressures (Y. Chen et al., 2019).

Even though the TOE framework is widely used to study aspects that play a role in technology adoption (Dwivedi et al., 2012), it is not specifically tailored to explain how technology adoption spreads within an organisation. The diffusion of innovations (DOI) theory, as postulated by Rogers (1995) is useful to understand how the adoption of technology spreads within an organisation. The definition of diffusion in the context of innovation theory is the process by which the adoption of innovative technology is communicated through certain channels over time among the members of a social system (Rogers, 1995). During the process of adopting innovative technology, individuals typically progress through five stages, namely the knowledge, persuasion, decision, implementation, and confirmation stages (Dwivedi et al., 2012). Furthermore, according to the DOI theory, prospective adopters of innovation assess technologies based on perceived attributes of the technology (Dwivedi et al., 2012), for example its relative advantage, compatibility with other systems, complexity, trialability and observed effects (Rogers, 1995).

Innovation diffusion theory and a TOE framework are not new to researchers. Innovation diffusion theory and a TOE framework have been successfully used in several studies (Nam et al., 2019; Wei et al., 2015; Wright et al., 2017; Zhu, Kraemer & Xu, 2006). For instance, Nam et al. (2019) used the innovation diffusion process to understand the business analytics adoption of organisations and the TOE framework to identify its drivers. As this study is interested in identifying the enabling factors for the organisational adoption of AI, a combination of the DOI and the TOE is also useful (Smit, Eybers, van der Merwe & Wies, 2023).

2.2 AI Adoption

Many AI adoption models have been developed to support organisations. For example, Mohapatra and Kumar (2019) shows how the different sociotechnical elements interact, specifically the data collection process, which is the input into machine learning, and machine learning creating insight. The model also shows how human judgement and physical intervention is sometimes required. In contrast, Bettoni et al. (2021) propose an AI adoption model with a more organisational focus, that includes digitisation, data strategy, human resources, organisational structure, and organisational culture as the main elements influencing adoption. Furthermore, Demlehner and Laumer (2020) highlight the relevance of environmental

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aspects, such as legal uncertainty regarding data protection, intellectual properties and liabilities, access to external expertise, and competitive pressure. Chatterjee et al.'s (2021) study on understanding AI adoption led to similar results; however, it highlights that leadership support is a supporting factor in moderating the adoption of AI. Leaders will not be able to support AI initiatives if they lack an understanding of AI and its capabilities (Berente et al., 2021). Organisational leaders should have the required knowledge to determine whether or not they should adopt innovation and to which degree (Rogers, 1995). It is, therefore, understandable that Demlehner and Laumer's (2020) study finds that there is a deep need for expertise in AI and that a lack of AI competence is the primary reason for the low adoption rate. Although these models are useful to recognise important aspects of adoption, they do not contain information on how this can be achieved and have not considered responsible AI adoption. In addition, even though organisations worldwide are ready to invest in AI to address their sustainability goals (IBM, 2022), none of the adoption models include any aspects to assist organisations in their sustainability targets.

From an industry perspective, organisations such as Amazon AWS, Google and Microsoft provide organisations with technology platforms supported by technical guidelines or frameworks to host and enable AI applications. For example, Amazon AWS's cloud adoption framework leverages AWS experience and best practices to help organisations digitally transform and accelerate their business outcomes through innovative use of AWS. This framework includes guidance on data curation, process automation, event management (AIOps), fraud detection and data monetisation (Amazon Web Services, 2021). Google Cloud's AI adoption framework covers aspects such as the power of AI, the creation of value and AI maturity (Google, 2022). Even though this framework seems to be comprehensive, Google Cloud's framework lacks social considerations, such as trust, ethics, and fairness (Crawford, 2021). Google has guidelines on responsible AI practices (Google, 2021). However, their adoption framework does not specifically mention them (Google, 2022). Microsoft does mention responsible and trusted AI as part of its cloud adoption framework (Microsoft, 2023). One aspect that is highlighted by the majority of the technological frameworks is the importance of ethical AI. Although important, not many organisations have actively focused on ensuring that AI is trustworthy (IBM, 2022). Organisations can also learn from their previous technological adoptions, including agile principles, encapsulation of shared code into functions and components, automated testing and continuous integration (Luckow et al., 2018).

What makes AI powerful is its technical capabilities. Nonetheless, the implementation of AI in organisations is not limited to the technical elements. An AI implementation within an organisation is a sociotechnical system, with the interplay between social and technical components (Wihlborg & Söderholm, 2013). When AI makes decisions that impact people, the sociotechnical considerations in AI adoption frameworks are paramount. Organisations do not only have the requirement to be successful in the technical aspects of AI implementations but also manage the social and environmental aspects.

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3 RESEARCH APPROACH

This study aimed to create a framework to support responsible AI adoption, bridging the gap between theory and practice (A. Hevner et al., 2010). Due to the objective to develop a framework of this nature, which is both of theoretical and practical value, this research followed a process of scientific rigour and is grounded in theory (Dresch et al., 2015). To allow for a systematic research and design approach, this study followed the DSR cycle steps as described by Vaishnavi et al. (2004) to create the AIAF. Peffers et al.'s (2007) includes similar steps; however, Vaishnavi et al.'s (2004) DSR cycle was selected for this study since it adopts a reduced process model and allows for a simple iterative approach. The TOE framework (Tornatzky & Fleischer, 1990) and the DOI theory (Rogers, 1995) provided the theoretical lens for this study. We employed a case study research method to construct the framework and followed a DSR main-cycle. The case study was conducted at an IT Hub. Three sub-cycles supported the DSR main cycle. All formed part of the same case study. The three sub-cycles focused on the socio-enabling factors for AI adoption (Smit, Eybers, de Waal & Wies, 2022; Smit, Eybers & Smith, 2022), the technical-enabling factors (Smit, Eybers & Bierbaum, 2022; Smit, Eybers & de Waal, 2022) and lastly a comparative analysis on the differences between adopting AI and adopting traditional data-driven technologies (Smit et al., 2024). In order to evaluate and develop the framework, further focus group sessions from the organisation's IT Hub were used. The focus groups comprised of domain experts in AI technologies. Additionally, the results of a systematic literature review on the critical success factors of AI adoption were used to enrich the findings (Hamm & Klesel, 2021). Figure 1 graphically depicts the research approach that was followed, and the DSR cycle content is described in detail in the artifact development section. To be of practical relevance, the developed framework addresses the challenges organisations face in adopting AI. Furthermore, the proposed solution not only highlights elements that influence adoption but should also include prescriptive knowledge (Baskerville et al., 2018) on how to enable organisational AI adoption.

4 DSR MAIN-CYCLE: ARTIFACT DEVELOPMENT

DSR is a methodology that enhances human knowledge and supports problem-solving by creating artifacts (A. R. Hevner et al., 2004). Constructs, methods, models and frameworks are all examples of artifacts that can be used to solve organisational problems (Dresch et al., 2015). In this study, the aim is to create a framework to support organisations with their AI adoption initiatives by following the DSR steps of Vaishnavi et al. (2004). The DSR steps are awareness of the problem, the suggestion of a solution, the development of a solution (artifact), the evaluation of the solution and, finally, a conclusion (Vaishnavi et al., 2004).

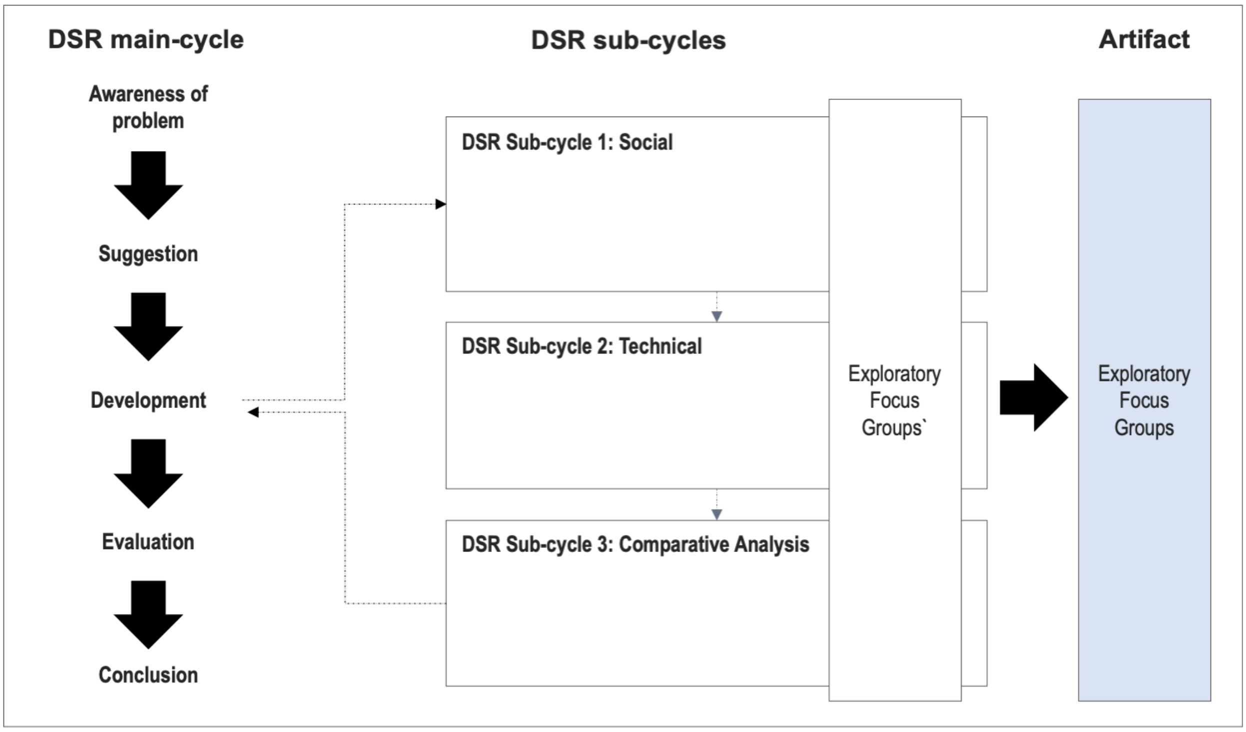


Figure 1: The three sub-cycles to designing an AIAF: Social[a], Technical[b], and Comparative Analysis[c].

[a] Smit, Eybers, de Waal and Wies (2022), Smit, Eybers and Smith (2022)
[b] Smit, Eybers and de Waal (2022), Smit, Eybers and van der Merwe (2023), Smit, Eybers and Bierbaum (2022)
[c] Smit et al. (2024)

4.1 Awareness of the Problem

The organisational adoption of technologies is a broadly researched topic (Lai, 2017). However, AI technologies have characteristics that make them unique, for example, it is often anthropomorphised (Salles et al., 2020) and it can learn and act autonomously (Berente et al., 2021). Additionally, AI cannot be referred to in a monolithic sense (Ågerfalk, 2020). AI can be classified based on intelligence (artificial narrow intelligence, artificial general intelligence and artificial superintelligence), based on technology (for example, machine learning, deep learning and natural language processing) or based on function (conversational, biometric, algorithmic and robotic) (Benbya & Davenport, 2020). Both scholars and industry agree that implementing AI in organisations will not replace humans in the short term but will instead enable augmented analytics within a human-AI symbiosis (human and machine partnership) (Herschel et al., 2020; Keding, 2021). The goal should be achieving full AI symbiosis, where AI can extend human cognition to address complex organisational decision-making (Jarrahi, 2018). The successful adoption of AI in organisations could lead to complex cybernetic collectives, that are far smarter than individuals. Moreover, in the quest for organisations to become more data-driven and adopt AI, organisations should be aware that AI, at a fundamental level, consists of not only the technical but also social practices (Asatiani et al., 2021) and also impacts the institutions, infrastructures, politics, and culture around it (Crawford, 2021). As a result, these complexities lead to several challenges, such as, AI's deployment problem, talent issues and social dysfunctions (Benbya & Davenport, 2020). Therefore, there is a need for a better understanding of the accepted approaches and techniques for managing organisational transformations into data-driven entities and the responsible adoption of AI. Furthermore, from the literature review, the social aspects are not well represented in the current AI adoption frameworks. The implications of neglecting AI's social aspects and impacts, for example, using the Earth's rare resources and cheap labour, with severe environmental and human costs, are well described in Crawford's book on 'ATLAS of AI' (Crawford, 2021).

4.2 Suggested Solution

The suggested solution should contain information on what influences the adoption and how to bring AI successfully into the organisation. Therefore, we propose combining the TOE framework to identify what influences the adoption and the DOI theory to investigate how to enable organisations to adopt AI. Furthermore, although not specific to AI adoption, several studies have successfully adopted the approach of combining DOI and the TOE framework (Wei et al., 2015; Wright et al., 2017; Xu et al., 2017).

Building on this theoretical basis, the proposed solution should address aspects related to the social and technical side of AI adoption in organisations. Organisations should also leverage their experience by adopting other traditional data-driven technologies. This should encompass information highlighting the similarities and differences between adopting artificial intelligence and these conventional data-driven technologies.

As mentioned in the research approach, in additional to the TOE (Tornatzky & Fleischer, 1990), DOI (Rogers, 1995) and the three aspects of AI adoption, a systematic literature review on the critical success factors of AI adoption is used to enrich the findings (Hamm & Klesel, 2021). The literature review used the TOE framework as the basis and identified 12 success factors related to the technological dimension, 13 related to organisational and 11 to the environmental dimension of the TOE framework (Hamm & Klesel, 2021).

4.3 Development of the Solution

As part of the development step of the DSR main cycle, this study uses three DSR sub-cycles. The first sub-cycle covers the social aspects of organisational AI adoption (social sub-cycle). The second sub-cycle covers the technical enabling factors related to AI adoption (technical sub-cycle) and the last DSR sub-cycle covers a comparative analysis to determine the similarities and differences between the adoption of artificial intelligence and traditional data-driven technologies (comparative analysis sub-cycle). The results of the three sub-cycles are consolidated into the AIAF and evaluated using industry focus groups. The DSR main-development step with its sub-cycles is graphically depicted in Figure 2.

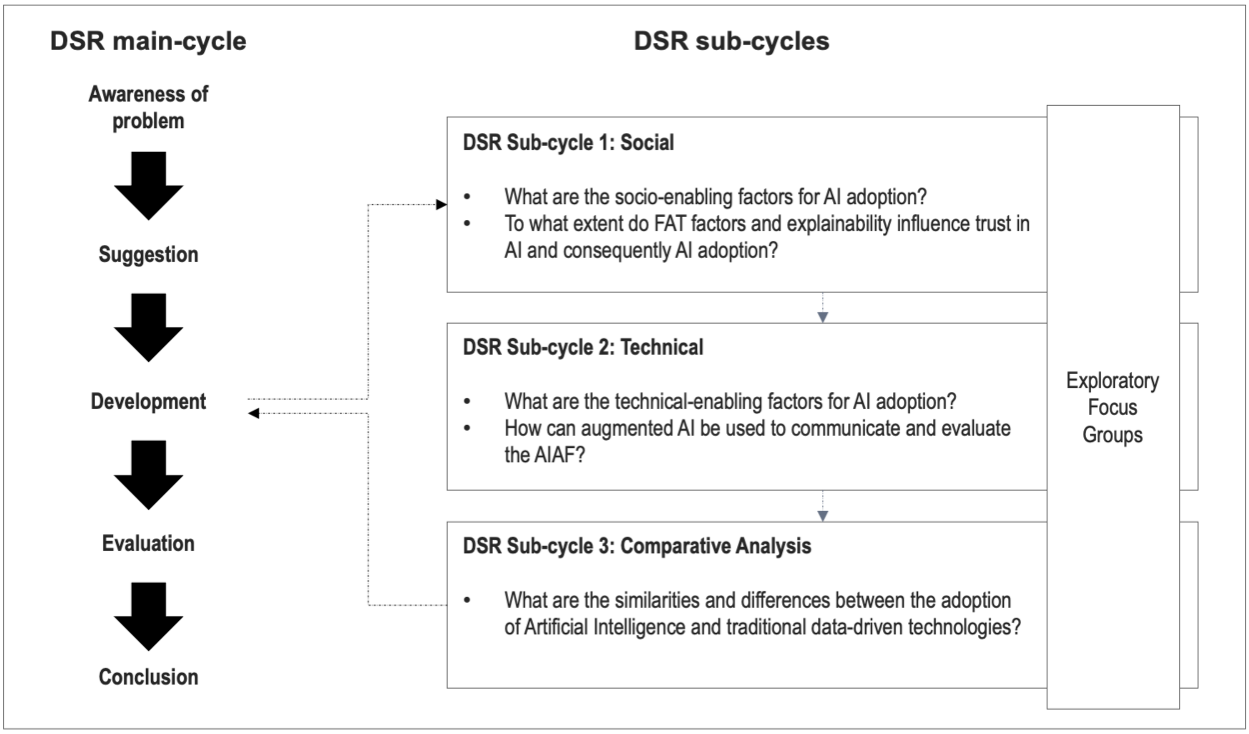


Figure 2: Sub-cycles to designing an AIAF

4.3.1 Sub-cycles

The **social sub-cycle** included two studies (Smit, Eybers, de Waal & Wies, 2022; Smit, Eybers & Smith, 2022), which focused on *'What are the socio-enabling factors for AI adoption?'* and given that ethical AI is fundamental to socially responsible organisations, *'To what extent do fairness, accountability, transparency (FAT), and explainability impact trust in AI, thereby influencing its adoption?'*. The first study used the DOI theory to identify the enabling factors contributing to the successful adoption of AI (Smit, Eybers, de Waal & Wies, 2022). It was based on the five stages of the innovation-decision process, as postulated in the diffusion of innovations theory (Rogers, 1995). Out of the study, it was clear that organisational AI adoption faces numerous barriers, for example, a lack of trust in AI, lack of technological understanding and costs related to hiring highly-skilled technical expertise. Increasing knowledge, highlighting benefits and removing impediments emerged as critical social enablers throughout the AI adoption decision stages (Smit, Eybers, de Waal & Wies, 2022). The second study applied the TOE framework (Tornatzky & Fleischer, 1990) and focused on the barriers to adoption, highlighting the extent to which fairness, accountability, transparency and explainability influence trust in AI and, consequently, AI adoption (Smit, Eybers & Smith, 2022). Online questionnaires involving analytics and AI experts were analysed using structural equation modelling (SEM) as the underlying statistical methodology. This study identified trust as one of the main barriers to adopting AI in organisations. Furthermore, it found that organisations that ensure fairness, accountability, transparency and explainability as part of their AI adoption initiatives will experience a higher level of adoption (Smit, Eybers & Smith, 2022).

The **technical sub-cycle** also contained two studies. The first focused on the technical aspects of the KAP-gap and investigated enabling factors to support the technical aspects of organisational AI adoption (Smit, Eybers & de Waal, 2022). It focused on answering the sub-question: *'What are the technical-enabling factors for AI adoption?'*. Surveys were used as the research method and were structured around innovation characteristics as postulated in the diffusion of innovation theory (Rogers, 1995). Topic modelling and the subjective analysis of the text corpus were applied to organise the response into 14 technical enabling factors. The second study (Smit, Eybers & Bierbaum, 2022) addressed the concern that the problems that organisations will face in the future are uncertain and that the exact requirements of artifacts are complex to predict (Simon, 2019). The sub-research question was *'How can augmented AI be used to communicate and evaluate the AIAF?'* In this study, an augmented AI solution was built to help continuously improve the AIAF. The solution first enables the AIAF communication to people in practice (Smit, Eybers & Bierbaum, 2022). It also allows for practitioners to evaluate and provide feedback to the AIAF owner. The improvement process is supported by an AI agent called Ailea[2] (Smit, Eybers & Bierbaum, 2022).

The **comparative analysis sub-cycle** included a study about understanding the similarities and differences between the adoption of AI and traditional data-driven technologies (Smit et al., 2024). The sub-research question was: *'What are the similarities and differences between the adoption of artificial intelligence and traditional data-driven technologies?'* As organisations have gained much experience implementing traditional data-driven technologies, they can lean on this experience. However, they can leverage this experience if they understand the differences between adopting traditional data-driven technologies and AI. This understanding can allow organisations to focus where it is required. To investigate the topic, a case study research approach was followed. The case study used surveys as a data collection method. The surveys targeted a combination of business intelligence experts (Group 1: 142 questionnaires were completed) and technical experts in AI (Group 2: 14 questionnaires were completed). Most technological, organisational, and environmental considerations were the same from the case study. However, the importance of democratising AI – while considering the autonomous capabilities of AI and the need for a more human-centred AI approach – became evident (Smit et al., 2024).

In order to develop the solution, the results of the three sub-cycles, together with the critical success factors (Hamm & Klesel, 2021), were combined into an AIAF (see Figure 1). There are six main areas covered in the developed AIAF. The first is an introduction to AI in a data-driven context, and the second is a high-level overview of facilitating the AI adoption

[2] Ailea is accessible on the website: http://www.ailea.co.za/.

decision process (Smit, Eybers, de Waal & Wies, 2022) and enabling factors to support the technical aspects of organisational AI adoption (Smit, Eybers & de Waal, 2022). Then AI adoption critical success factors based on the TOE framework (Hamm & Klesel, 2021; Smit, Eybers & Smith, 2022). And lastly a summary of the differences between AI and traditional data-driven technologies, such as business intelligence (Smit et al., 2024).

4.3.2 AI in a Data-Driven Organisation

As traditional organisations are struggling to implement AI as part of their analytics portfolio, the goal is that the AIAF provides organisations with a high-level guide to assist in adopting AI and transforming it into more data-driven solutions. In the context of the AIAF, a data-driven organisation is defined as an organisation that uses analytical tools and abilities, that creates a culture to integrate and foster analytical expertise and acts on observed data to achieve benefits (Smit, Eybers, de Waal & Wies, 2022). The idea is not that AI replaces humans, but rather that AI can support data-driven organisations within a human-machine partnership (Herschel et al., 2020; Keding, 2021) while supporting or automating some decision-making (Benbya & Davenport, 2020). Furthermore, true data-drivenness should include forward-looking analysis, where organisations not only use data to report on the past but utilise models to predict the future in a responsible manner (C. Anderson, 2015).

4.3.3 Facilitating the AI adoption decision process

The adoption decision stages are the phases that potential adopters of AI will go through when deciding to adopt AI as part of their analytics portfolio. The stages are to increase knowledge of AI, form an attitude towards AI (persuasion stage), make a decision to adopt or reject the use of AI, then to implement AI (or not implement AI), and lastly, confirm and evaluate the decision (Smit, Eybers, de Waal & Wies, 2022). In the AIAF, each phase contains the enabling factors related to the phase and can be used by organisations to support their AI adoption initiatives. As AI technologies are ever evolving, the stages can be repeated in cycles (see Figure 3).

The framework shows each decision-making stage and the enabling factors that support adoption (see Figure 4). Increasing the knowledge of AI in organisations is the first stage of the innovation-decision process and occurs by exposing an individual or an organisation to an innovation to increase the awareness of the innovation. The communication of abilities, benefits and limitations when adopting the technology should be done to the potential adopters and decision-makers of AI (Smit, Eybers, de Waal & Wies, 2022) employees and management (who are the adopters and decision-makers) (Smit, Eybers, de Waal & Wies, 2022). This can be achieved via numerous channels, for example, forums, workshops, and training (Smit, Eybers, de Waal & Wies, 2022). Training is a key enabler to build more capabilities in AI (Chui, 2017) and should not only include awareness of AI but also how-to and principles knowledge (Rogers, 1995). Training initiatives should include training on AI tools, training on AI platforms, and training covering AI products and AI concepts (Smit, Eybers, de Waal & Wies, 2022). The

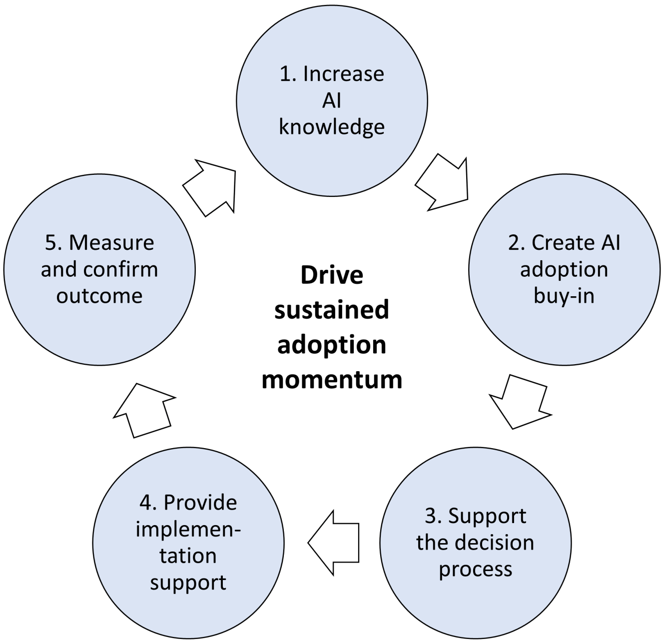


Figure 3: Stages to facilitate the AI adoption decision process

training should be focused not only on employees but also on management (Rogers, 1995), as knowledge in AI is a precondition for creating strategic value from AI (Keding, 2021). Additionally, communities of practices (COP), pilot or lighthouse projects, outsourcing and analytics competence centres can be used to gain knowledge and communicate (Smit, Eybers, de Waal & Wies, 2022).

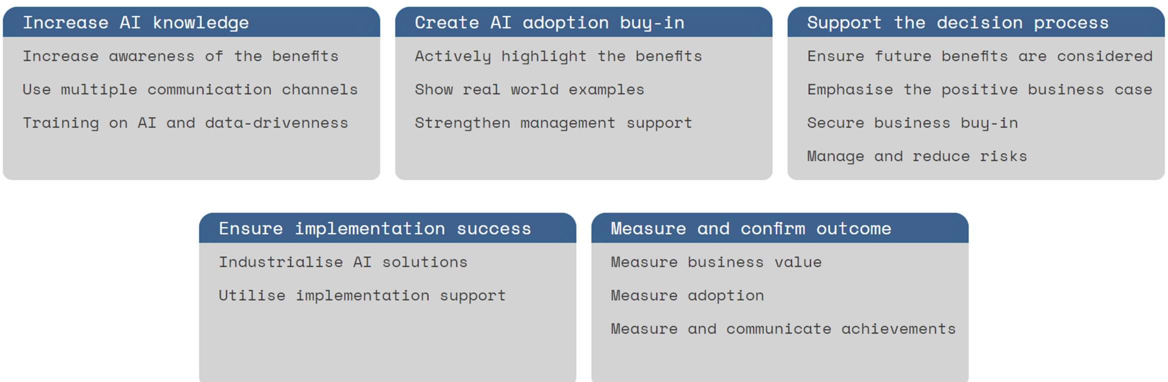


Figure 4: Enabling factors to facilitate the AI adoption decision process

The main goal of the next stage is to develop a favourable attitude towards innovation. Many organisations may know innovations but have not adopted them yet. This stage includes highlighting the benefits of adopting AI. The same types of communication channels can achieve this during the knowledge phase. It is important to enable the organisation to grasp the importance and benefits of AI's use. One method to accomplish this is to use champions within an organisation. These champions can share previous achievements and communicate benefits to other potential adopters (Smit, Eybers, de Waal & Wies, 2022). Showing real-life examples will also boost confidence in AI and can be achieved by using workshops, demos and pilots (Smit, Eybers, de Waal & Wies, 2022). Lastly, the importance of top management support should not be underestimated (Dremel et al., 2017). The benefits and limitations when adopting AI should be known by management in order for them to support and encourage the adoption of AI (Smit, Eybers, de Waal & Wies, 2022).

In the 'decision to adopt stage', the individual weighs the advantages and disadvantages of adopting the innovation and forms an intent to adopt or reject the innovation (Rogers, 1995). It is not only an adoption decision, but a financial investment, therefore the future benefits and a positive business case is key to the adoption decision process (Chui, 2017). Furthermore, the reduction of risks is also an enabling factor, such as addressing issues of trust, explainability and fairness (Smit, Eybers & Smith, 2022).

There is a difference between the decision to adopt AI and to implement it. During the implementation stage, the organisation puts AI into use (either implementing successfully or unsuccessfully). Therefore, the specific focus is on increasing the probability of a successful go-live or implementation. This includes aspects such as involving business and getting implementation support from external providers if the specific knowledge of AI is not within the organisation (Smit, Eybers, de Waal & Wies, 2022). AI implementations have multiple challenges, like user resistance, skills shortages and substantial data engineering requirements (Smit, Eybers, de Waal & Wies, 2022).

The 'confirmation stage' of AI adoption deals with the confirmation and continuation of AI adoption. Therefore, it evaluates business value and goal achievement (Smit, Eybers, de Waal & Wies, 2022). This is important as some people in the organisation might view the business case for adopting AI as unproven, and hence might be reluctant to take the first step towards adoption (Bughin & Van Zeebroeck, 2018). The measurement of business value, the level of AI adoption, and the level of goal achievement are all enabling factors to confirm if AI adoption was satisfactory (Smit, Eybers, de Waal & Wies, 2022). The confirmation stage includes integrating the innovation into one's routine and promoting it to others, which could trigger the next cycle and start again with increasing knowledge.

As AI is a moving target and at the frontier of computational advancements (Berente et al., 2021), AI adoption should be seen as a continuum. As a result, it is essential to conserve AI adoption momentum by implementing a continuous improvement mindset. This can be supported by an innovative company culture (Chui, 2017; M. C. Lacity & Willcocks, 2021), by ensuring that the value of adopting AI is known (Smit, Eybers, de Waal & Wies, 2022) and constantly removing barriers that might hamper the adoption process (Chui, 2017).

The technical enabling factors related to the four main areas are summarised in Figure 5. The first is the importance of having a business case for implementing and adopting AI. This can be achieved by AI technologies that can make automated informed decisions and poten-

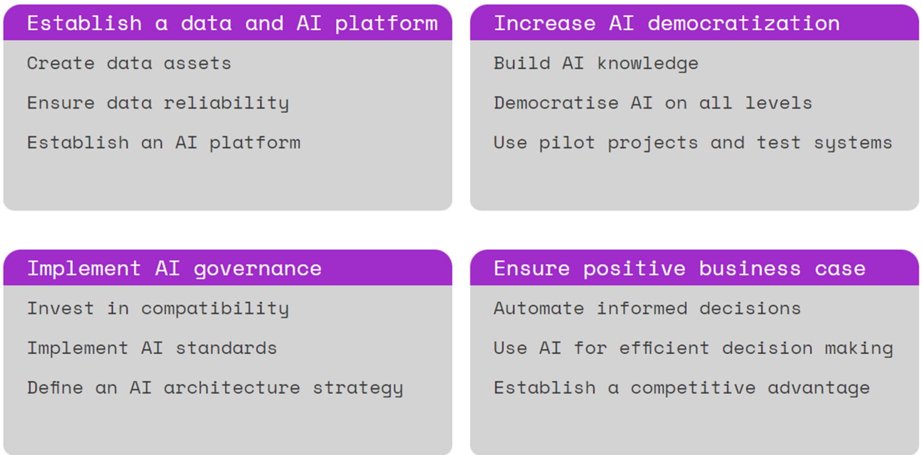


Figure 5: Technical enabling factors to support AI adoption [a]

[a] Smit, Eybers and de Waal (2022)

tially lead to more efficient decision-making. Secondly, organisations should ensure proper IT governance (Smit, Eybers & de Waal, 2022), via governance bodies (Ienca, 2019) and operational processes, for example, MLOPS (Liu et al., 2020). Enabling aspects include the investment in compatibility, implementing standards and developing and following an architecture strategy. Thirdly, achieving the democratisation of AI in organisations is essential. This can be achieved by providing people access to test systems and allowing for pilot projects (Smit, Eybers & de Waal, 2022). The fourth area relates to the enterprise data platform to support analytics and AI. This includes organisational-wide data asset capability, increasing data reliably and processing power (Davenport & Harris, 2010; Wixom et al., 2021). The proposed technical-specific aspects are summarised in Figure 6. This figure is derived and based on the technical enabling factors. However, the figure has a platform focus and more depth (Smit, Eybers & de Waal, 2022).

4.3.4 Critical success factors for AI adoption

The critical success factors were derived from the TOE framework (Tornatzky & Fleischer, 1990). The AI TOE considerations are the technological, environmental and organisational elements that organisations should consider and relate to the critical success factors when adopting AI (Hamm & Klesel, 2021). The AI adoption success factors are summarised in Figure 7. From a technological point of view, organisations should ensure that the needed IT infrastructure is in place (Hamm & Klesel, 2021). This involves setting up the required data ecosystem and buying or building the appropriate AI tools (Chui, 2017). It should be done in such a way that it can lead to a relative advantage for the organisation (Hamm & Klesel, 2021). Furthermore, the characteristics of the technology should allow for observabil-

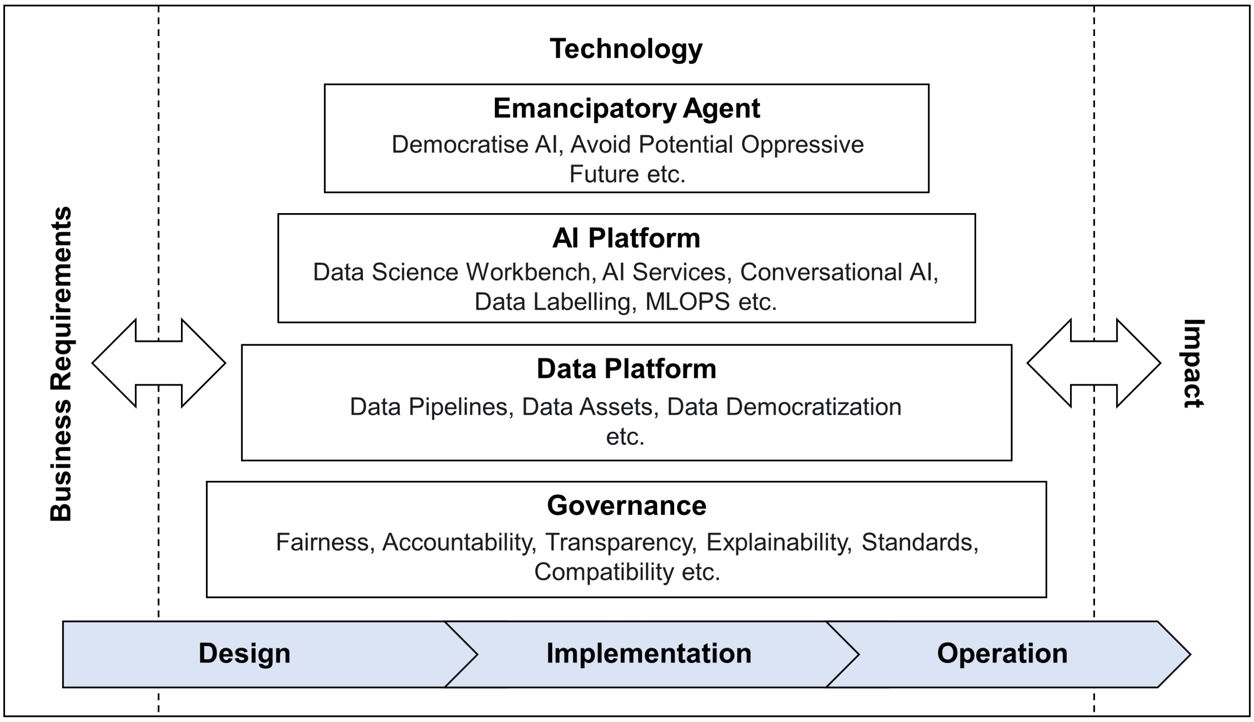


Figure 6: Technical Specific Factors [a]

[a] Smit, Eybers and de Waal (2022)

ity, which enables transparency and explainability (Smit, Eybers & Smith, 2022). AI solution development should be done in a manner that renders the models more understandable to stakeholders and addresses AI interpretability needs (Asatiani et al., 2021). Top management support (Chui, 2017) and access to the required skills, competencies, and resources are some organisational success factors in adopting AI (Hamm & Klesel, 2021). Additionally, in the context of an organisation's subjective norms, ensuring fairness in AI is another organisational consideration (Smit, Eybers & Smith, 2022). Also, considerations such as slack (Rahrovani & Pinsonneault, 2012), absorptive capacity (Trantopoulos et al., 2017) and culture (Davenport & Bean, 2018) play an important role in adoption. A competitive environment is one of the main factors influencing organisations to adopt AI (Hamm & Klesel, 2021). Aspects such as governmental regulations, customer readiness and industry pressure are other examples of critical environmental considerations for organisations when striving to adopt AI (Hamm & Klesel, 2021). Additionally, aspects such as a regulatory environment insist that the organisation's accountability is set in place (Smit, Eybers & Smith, 2022). Lastly, AI also impacts its environment; the energy consumption of running large-scale AI deep learning models should not be underestimated, and the environmental impact thereof cannot be ignored (Crawford, 2021). For socially responsible organisations, managing energy consumption becomes a success factor.

Technological	Organisational	Environmental
IT infrastructure	Top management support	Industry pressure
Tool availability	Competencies	Trust
Transparency	Resources	Accountability
Explainability	Fairness	Governmental regulations
Learning and autonomous capabilities	Absorptive capacity	Customer readiness
Quality data	Culture	

Figure 7: Critical success factors to enable AI adoption

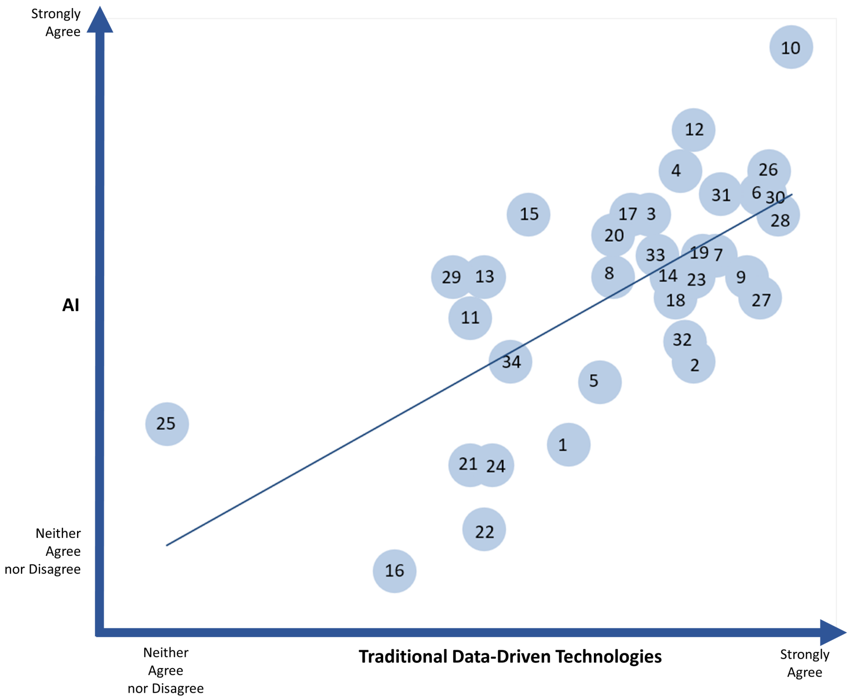
4.3.5 Differences between AI and Traditional Data-driven Technologies

Understanding the similarities and differences between adopting more 'traditional' data-driven technologies and AI can benefit managers within organisations, as this information will allow them to use their experience from adopting other traditional data-driven technologies and assist them in understanding the essential differences. Most TOE considerations related to traditional data-driven technologies and AI are the same. However, some fundamental and impactful differences exist (Smit et al., 2024). Figure 8 shows the differences between AI and traditional data-driven technologies (Smit et al., 2024). None of the TOE factors were ranked as 'not relevant' (Disagree).

Traditional data-driven technologies are easier to understand than AI, which leads to the challenge of building AI knowledge and democratising AI (Alfaro et al., 2019). Furthermore, traditional data-driven technologies are more human-centred than AI (Shneiderman, 2020). For this reason, the human aspects of AI adoption should take special care, for example, ensuring ethical AI and preserving human control over AI. Lastly, AI can learn and act autonomously, and this gives AI the ability to lead to a lot of efficiencies potentially. However, the impact of AI and automation on humans must be considered, especially when considering the potentially oppressive nature of AI (Russell, 2019). Figure 9 graphically depicts the critical considerations regarding the differences between traditional data-driven technologies and AI.

4.4 Evaluation of the Solution

The proposed AIAF was evaluated through four exploratory focus groups (Tremblay et al., 2010) with six participants each. The focus group sessions occurred in 2022 and spread over eight months throughout the sub-cycles. The four focus group sessions were conducted at the same IT Hub previously mentioned (Smit, Eybers & Bierbaum, 2022; Smit, Eybers & de Waal, 2022; Smit, Eybers, de Waal & Wies, 2022; Smit, Eybers & Smith, 2022; Smit et al., 2024). Focus group sessions were used as a method to improve the framework based on their expertise. Using focus groups from industry is of value to this study as it puts the researchers in direct interaction with domain experts and potential users of the framework (Tremblay et al., 2010), with the shared target to maximise knowledge, wisdom, and creativity (Wickson et al., 2006). The participants of the focus groups were selected based on their domain expertise, and as the



Nr	TOE Factor
1	Accountability
2	Availability of new innovations
3	Competitive pressure
4	Defining scope
5	Fairness
6	Financial commitment
7	Financial resources
8	Having a change champion
9	Infrastructure
10	Management support
11	Market uncertainty
12	Organizational readiness
13	Perceived barriers to technology
14	Perceived benefits or technology
15	Perceived financial cost
16	Perceived government pressure
17	Perceived industry pressure
18	Perceived technology simplicity
19	Perceived technical competency
20	Performance gap
21	Regulatory environment
22	Regulatory support
23	Risk appetite
24	Satisfaction of existing systems
25	Size of organization
26	Strategy
27	Technology compatibility
28	Technology competence
29	Technology complexity
30	Technology integration
31	Technology readiness
32	Transparency
33	Trialability
34	Vendor support

Figure 8: Technological, organisational and environmental factors influencing adoption [a]

[a] Smit et al. (2024)

study is focusing on the 'how', the participants included both technology and management-orientated experts (Dresch et al., 2015). Specifically, the groups comprised of a mixture of site reliability engineers, agile masters, data engineers, business intelligence professionals, data scientists, IT governance experts, technical team leads and management.

As SCRUM is part of the organisation's agile working model, it was decided that the focus group sessions should be conducted in the form of sprint reviews (Gonçalves, 2018). A sprint review typically includes the evaluation regarding what has been achieved during a sprint, in this case, the AIAF (Gonçalves, 2018). The concept of using sprints to harden the scientific rigour of DSR was introduced by Conboy et al. (2015); however, using actual sprint reviews to evaluate artifacts is a novel research method. In contrast, applying sprint reviews to evaluate artifacts is commonly used in practice. Due to the transdisciplinary nature of this research, the novel idea of combining focus groups and sprint reviews is appropriate (Wickson et al., 2006).

The AIAF was shared with the focus group participants a few days before the actual sessions. Ailea (Smit, Eybers & Bierbaum, 2022) communicated the framework and enabled the focus

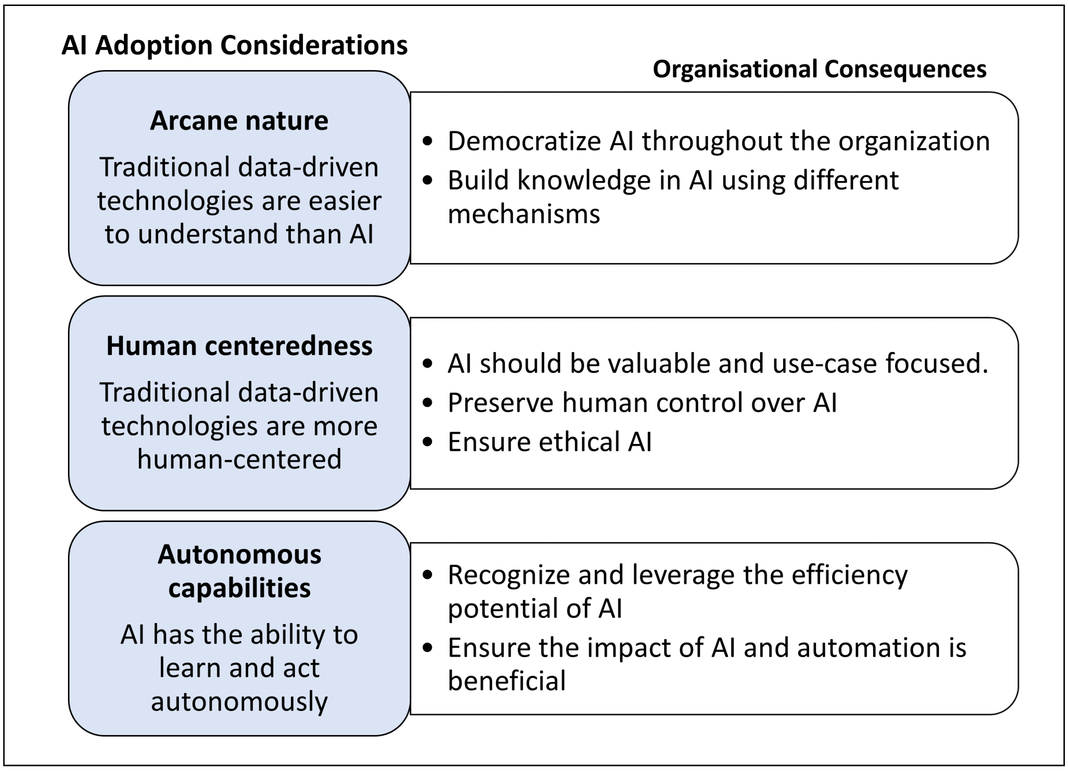


Figure 9: Considerations regarding the differences between traditional data-driven technologies and AI [a]

[a] Smit et al. (2024)

group members to provide preliminary feedback on the framework. Ailea is an augmented artificial intelligence tool, that was specifically developed to assist in communicating and improving the AIAF (Smit, Eybers & Bierbaum, 2022) (see Figure 10).

For the focus group sessions, the feedback via Ailea was used as input to the discussion, and Conceptboard was used to support the collaboration and document the results for analysis. Conceptboard is an online tool for collaborative engineering design by a geographically separated team (M. Anderson et al., 2022). Figure 11 is a screenshot of the last focus group session using Conceptboard (M. Anderson et al., 2022). The area in pink on the top above the dotted line is used to present the framework to the participants. This contains the background, problem statement, the session objective, and an overview of the framework. The area in blue below the dotted line allows the participants to provide feedback. The screenshot is intended to show a high-level view of the board and the content is described below.

All the focus groups indicated that AI is different from standard systems. They pointed out that this is because, in AI, continuous 'learning' takes place based on data, compared to standard systems, which are more rule-based. Furthermore, they stated that AI encapsulates a computer-based ecosystem that aids in automation, analytics, and creativity. They addi-

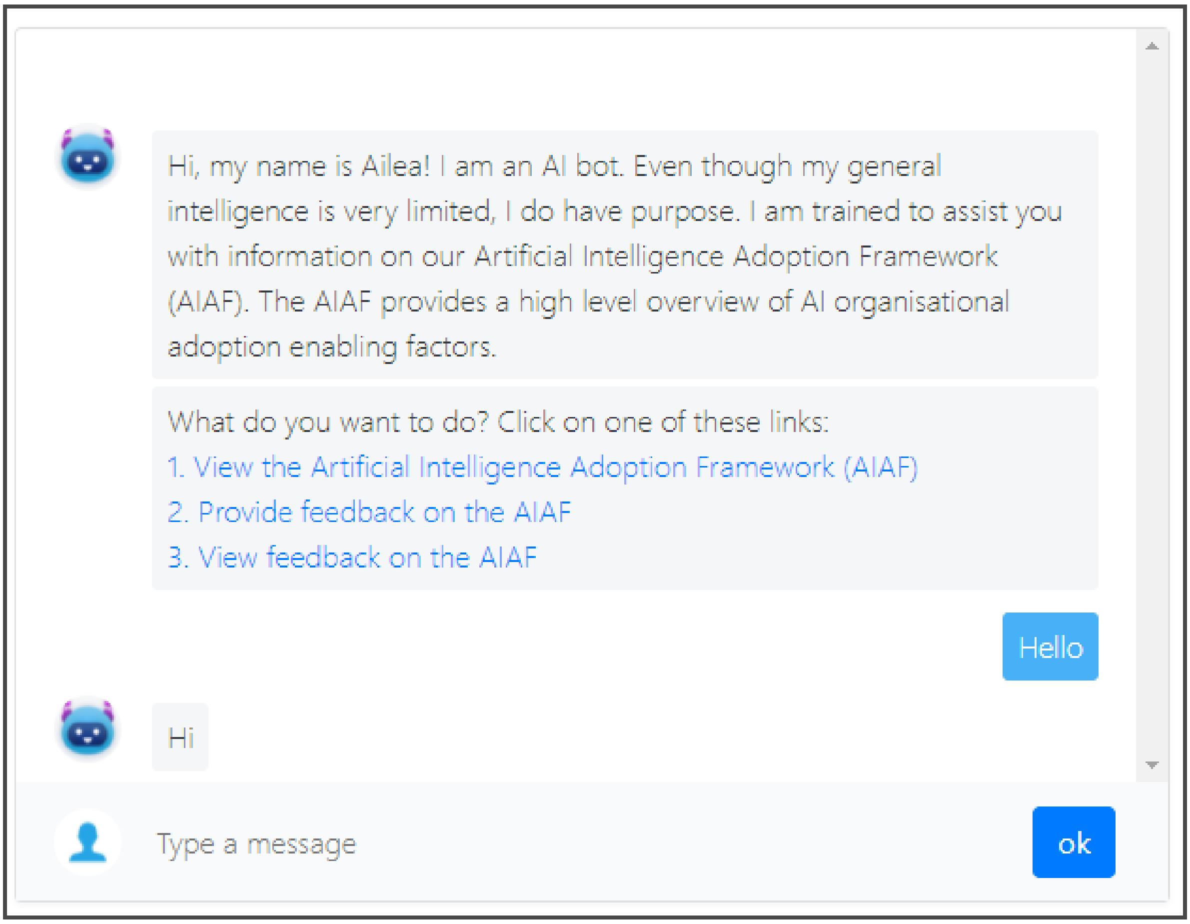


Figure 10: Using augmented AI to communicate, evaluate and improve the AIAF

tionally highlighted that AI is comprehensive and ever-growing. This benefits data analytics because it is unconstrained but presents its own risks, such as algorithm bias. The focus group participants recommended that the limitations of AI in the use of analytics be explained. A participant from the focus group, who trained business units and senior management on AI potentials, noted that many managers emphasised the need to clarify the value or benefits of AI. This is in line with the proposed AIAF that includes the benefits and value of AI in all but one adoption decision stage, especially including information on what type of problems can be solved with AI that can't be solved with traditional methods. The importance of highlighting the benefits of adopting AI is in line with the findings of previous studies (Smit, Eybers, de Waal & Wies, 2022; Tornatzky & Fleischer, 1990). The data scientists emphasised that the limitations of AI must also be made clear. Additionally, the democratisation of AI triggered discussions among data scientists. The concern was that not all people can implement machine learning responsibly. The discussion concluded that for this group, the democratisation of AI referred to allowing all entities in the organisation access to the value of AI. When it comes to

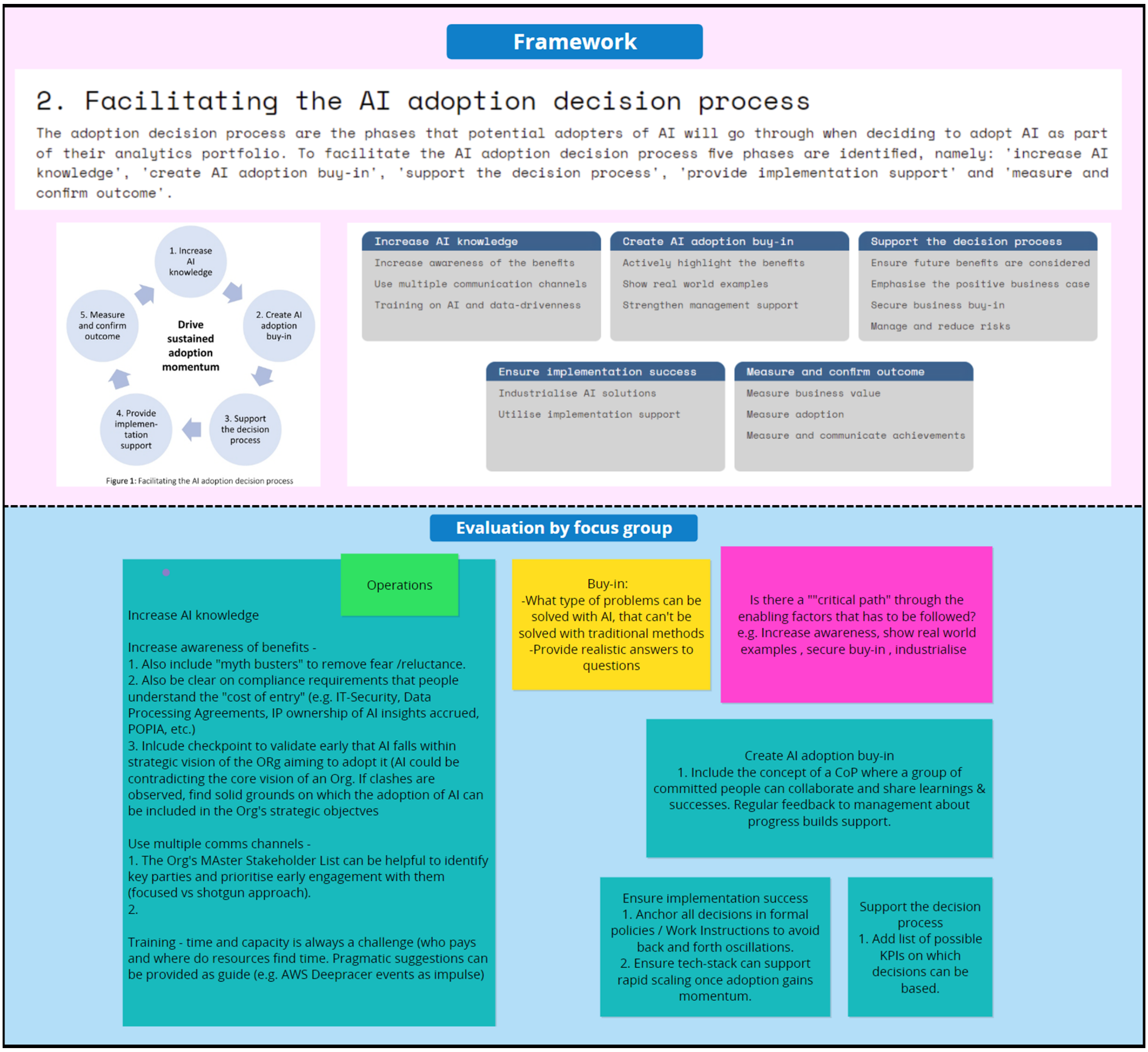


Figure 11: Screenshot of the Conceptboard tool used during a focus group session

building AI solutions, the required governance and controls should be put in place.

The focus groups further pointed out that the fundamentals of data-drivenness should be in place. This includes the quality and amount of data, which confirms the findings of other research related to different industries (Hamm & Klesel, 2021; Pillay & Van der Merwe, 2021). Additionally, one data scientist mentioned that more complex data structures will usually need more data to train a proper model. Over and above this, documentation is highlighted as necessary due to AI's complexity. One focus group participant mentioned: *'I believe that the documentation of AI implementation is crucial for operations, handovers and improvements'*. Other fundamental aspects include a scalable infrastructure, and standard continuous integration (CI) and continuous delivery (CD) concepts. CI allows for automatically testing code and CD supports pushing code into production (Treveil et al., 2020).

The focus groups participants agreed with the findings that fairness, accountability, transparency (FAT) and explainability in AI processes lead to trust and a higher rate of AI adoption (Smit, Eybers & Smith, 2022). Additionally, experts in the focus group highlighted that to ensure AI is implemented responsibly, the FAT factors and explainability should be incorporated into the teams' daily work and not be an afterthought. The group suggested that fairness, accountability, trust and explainability should be included in the organisation's governance process. This suggestion aligns with the recommendations from Ienca (2019), who advocates that it is the responsibility of technology governance bodies to align the future of cognitive technology with democratic principles, such as fairness, accountability and transparency. Another focus group recommendation is adding an AI ethics board within organisations.

When evaluating the proposed framework, all focus groups agreed that the framework is useful as a high-level guide to help organisations on how to enable them to adopt AI. They did however point out that the target group of the adoption framework should be made clear, being managers of traditional enterprises. Some comments on the framework from a data scientist: *'Regarding the adoption stages, I believe, from a data-driven organisation point of view, the stages provided in your table are wholesome and complete. I believe such an organisation would also require a general framework within the implementation phase so that there are guidelines and standards to which the AI systems need to adhere to. This will be vital to ensure that AI use cases are streamlined according to managed guidelines and standards and prevent entropy, discord, and redundancy amongst and between developers and business units'*. One data scientist endorsed the framework; however, emphasised the importance of possessing the appropriate development, platform, and operational expertise (organisational competency and resources).

4.5 DSR Cycle Conclusion

The focus group sessions with Ailea (an augmented AI chatbot) were used to communicate and gather practitioner feedback. From the feedback, it was clear that the framework was understandable and usable by practitioners to assist them in responsibly adopting AI. However, some enhancements were recommended, such as a narrower definition of AI, including governance processes (Ienca, 2019), and more focus on industrialisation and machine learning operations (Treveil et al., 2020). Furthermore, it is recommended to consider making the value-creating steps occur in a tight sequence so that the product or service will flow smoothly toward the customer, which can be achieved via CI and CD (Treveil et al., 2020). Additionally, the framework can be enhanced by stating its objective and target group, which aligns with Pee et al.'s (2021) findings.

5 SUMMARY OF FINDINGS AND IMPLICATIONS

This study describes an iteration of a DSR cycle that includes three sub-cycles. The research question under investigation was: *From a sociotechnical perspective, how can an organisation increase adoption of AI as part of its quest to become more data-driven?* On the theoretical bases of DOI and the TOE framework, together with three related studies, an AIAF was created. The AIAF is a high-level guide to support organisations' AI adoption journeys. Using augmented AI and exploratory focus groups, the AIAF was evaluated, and recommendations for improving the framework were provided. However, it should be mentioned that the concept of a framework alone cannot increase AI adoption. Organisations will have to successfully apply the framework to responsibly increase AI adoption.

Additionally, implementing AI in a fair, responsible, ethical and trustworthy environment requires attention. It is essential that these issues are highlighted to potential adopters during the awareness stage of the adoption decision process. The organisation where the study took place has seven principles covering the development and application of AI, namely: 'human agency and oversight', 'technical robustness and safety', 'privacy and data governance', 'transparency', 'diversity', 'non-discrimination and fairness', 'environmental and societal well-being' and 'accountability'. It was interesting to observe that the seven principles were well represented in the AIAF and the recommendations from the focus groups.

The study highlighted sociotechnical aspects to consider when adopting AI in organisations. Even though other AI adoption frameworks exist, the socio-specific considerations or impact of adopting AI are not sufficiently addressed by the frameworks (Bettoni et al., 2021; Google, 2021; Mohapatra & Kumar, 2019; Pillay & Van der Merwe, 2021) mentioned in Section 2.2. The expected contribution of the AIAF artifact is two-fold. By highlighting the sociotechnical considerations, on the one side, the framework can be used by academia and provides a high-level view of identified social elements essential for enabling the responsible adoption of AI. On the other hand, the framework offers practitioners a high-level guide, assisting managers and change mediators in promoting responsible AI adoption and transitioning traditional organisations to data-driven entities. Unlike the other frameworks mentioned in Section 2.2, this study, through the DSR approach, explains how the framework was developed and evaluated. The study also demonstrated how augmented AI allows a machine-human partnership to communicate, evaluate and improve the AIAF (Smit, Eybers & Bierbaum, 2022). Additionally, agent Ailea is prompting the evaluators of the AIAF to consider the potentially oppressive environment as a result of implementing AI in organisations.

6 CONCLUSION

The study proposes a sociotechnical framework for the organisational adoption of artificial intelligence (AIAF)[3]. A design science research (DSR) approach was followed to design the framework, constituting various iterative cycles and aimed to capture concrete, contextual, in-depth knowledge about a specific real-world organisation. The theoretical component of the paper was formulated by combining information systems theories, such as the TOE framework and DOI theory, with existing industry concepts, such as SCRUM review sessions, collaboration tools, such as Conceptboard, and the idea of using augmented AI to communicate, evaluate and improve DSR artifacts (Smit, Eybers & Bierbaum, 2022). Focus groups served as the primary research method. In essence, the scope of this study was limited to one IT Hub. However, the creation of the framework is grounded in sound information system theory, and the organisation in question maintains a very high digital transformation maturity and experience. Therefore, the experience and findings – though limited in their extent – can be implemented by other organisations to support the responsible adoption of AI as part of their analytics portfolio.

In conclusion, the implementation of AI can offer significant advantages to organisations. But, given the potential risks it poses to human well-being, AI must be deployed fairly, responsibly, ethically, and trustworthily. The transformative capabilities of AI cannot be ignored, highlighting the evolution's relevance towards human-AI symbiosis. The designed framework includes the following core human-AI symbiosis concepts: awareness of benefits and risks, governance processes, implementation of an AI ethics board and ethical organisational culture.

The subject's significance warrants further research, especially in evaluating the framework's applicability across diverse companies and industries. For instance, comparative analysis across sectors would show how the sociotechnical framework performs in varied organisational contexts supporting human-AI symbiosis. Furthermore, explorations into augmented AI's role in organisational communication and artifact evaluation also present promising avenues for study.

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Research Article

Understanding the inertial forces impeding dynamic cybersecurity learning capabilities: The case of a South African healthcare software services firm

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ABSTRACT
Healthcare firms need to develop cybersecurity learning mechanisms to respond faster and more proactively to a rapidly changing cybersecurity threat landscape. Many healthcare firms lack the necessary cybersecurity learning capabilities to address ever-changing and unpredictable cyberthreats effectively. In this case study, we investigate the challenges faced by a major South African healthcare software services firm that offers software as a service (SaaS) solutions. We analyse the inertial forces that impede the firm's cybersecurity learning capabilities by integrating concepts from dynamic cybersecurity learning capability (DCLC) and IS-enabled organisational learning perspectives. Furthermore, we identify strategic and operational level inertial forces through interviews with the organisation's experts and examination of cybersecurity documents. We then present actionable recommendations for industry practitioners to overcome these inertial forces and strengthen their cybersecurity learning capabilities. Our suggested interventions include implementing proactive leadership structures, enhancing user learning capabilities, and adopting novel risk management approaches. Additionally, we propose further directions for scholars to research the impact of inertial forces on dynamic cybersecurity learning capabilities in healthcare firms.

Keywords case study, cybersecurity, dynamic capabilities, organisational learning, organisational inertia, healthcare, software as a service

Categories • **CCS ~ Security and Privacy, Human and societal aspects of security and data privacy, Privacy**

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1 INTRODUCTION

Cybercriminals are working with increased sophistication, constantly learning new ways to target and evade detection by healthcare organisations (Martin et al., 2017). The repercussions

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of cyberattacks on healthcare institutions are gaining prominence within the cybersecurity domain (Renaud & Ophoff, 2019). The escalating awareness of these consequences underscores the urgency for healthcare organisations to adopt proactive measures to safeguard against cybersecurity threats (Renaud & Ophoff, 2019). However, the inherent challenges of improving existing systems due to inertial forces are hindering the ability of healthcare organisations to respond effectively to cybersecurity threats (Frumento, 2019).

Healthcare organisations must proactively adapt and reinforce their cybersecurity capabilities to safeguard against cybercriminals who continuously develop sophisticated cyberattack techniques (Appari & Johnson, 2010). Cybercriminals take advantage of the interconnected nature of modern healthcare organisations to launch lateral movements to gain access to other vulnerable systems (Graham, 2021). Moreover, cyberattackers often operate from systems not directly under their control, making detection and prosecution arduous (Papastergiou et al., 2021). It is, therefore, imperative for healthcare organisations to adapt cybersecurity capabilities to counter advanced cybercriminals.

As the healthcare sector adopts wearable devices, telehealth, and Internet of Things (IoT) technologies, these give rise to distinct attack vectors, wherein cyberattacks on life-saving devices could have severe and life-threatening consequences, especially for patients with chronic illnesses (Graham, 2021; Sparrell, 2019). Consequently, cyberattacks within the healthcare sector have escalated into a life-and-death phenomenon, emphasising the importance of adopting proactive cybersecurity measures.

Novel multi-stage attacks, such as Advanced Persistent Threat (APT) attacks, further exacerbate the challenges of combating cyberthreats (Papastergiou et al., 2021). Additionally, the barriers to entry for cybercriminals have significantly lowered, as they now have access to malicious tools and services through the dark web (Papastergiou et al., 2021). In the face of this dynamic cybersecurity threat landscape, static industry standards and frameworks, like the NIST Cybersecurity Framework and ISO 27000 series, struggle to keep pace with evolving threats and rapidly changing technology (Scofield, 2016).

To fortify their cybersecurity defences and effectively counter ever-changing cyberattackers, healthcare organisations should adopt a dynamic approach. We propose integrating concepts from dynamic capabilities theory, organisational learning, and organisational inertia to supplement and inform the development of existing cybersecurity standards and frameworks. Emphasising the need for a dynamic cybersecurity learning framework, we contend that healthcare organisations that embrace these principles will be better prepared to withstand rapidly evolving cyberattacks.

We assert that a deeper understanding of inertia is the first crucial step to addressing the inertial forces that impede the building and implementation of Dynamic Cybersecurity Learning Capabilities (DCLC). By comprehending the forces of inertia that hinder the development of DCLC in a South African healthcare software services firm, the firm can proactively counteract these inertial forces and foster a more responsive cybersecurity culture. Therefore, we propose the following research questions to guide our investigation:

What are the major inertial forces that can impede the building of dynamic cybersecurity *learning capabilities in a South African healthcare software services firm, and how can these inertial forces be effectively counteracted by key cybersecurity learning drivers?*

The remainder of this article is structured as follows: We provide an overview of the cybersecurity challenges facing South African healthcare organisations. Subsequently, we outline the theoretical foundations for our healthcare software as a services case study, drawing upon key concepts from organisational learning, organisational inertia, and dynamic capabilities theories. We then present our research methodology and findings, followed by a discussion of our research's contributions, implications, and limitations.

2 CYBERSECURITY CHALLENGES IN SOUTH AFRICA

The African continent is experiencing a significant upsurge in cybersecurity threats. Notably, a 2018 report by Symantec Incorporation highlighted that cybercrime increased faster in Africa than on any other continent (Walker et al., 2021). The economic impact of cybercrime in South Africa alone is estimated to range between R8.5 billion and R10 billion (Adomako et al., 2018; Gopal & Maweni, 2019). In 2020, cybercrimes ranked fourth in the most frequently reported criminal activity and exhibited the most rapid growth rate in South Africa (Walker et al., 2021). The COVID-19 pandemic further exacerbated the situation, with numerous healthcare institutions falling prey to coordinated cyberattacks, including those in South Africa. Table 1 offers a glimpse of some significant cyberattacks that have targeted healthcare organisations since the onset of the COVID-19 pandemic.

Table 1: Cybersecurity breaches in the healthcare sector since the onset of COVID-19

Date of cyberattack	Country/ Institution	Reported details
30 July 2020	South Africa – Life Healthcare	A coordinated cyberattack disrupted IT services. However, the complete extent of the attack was not publicly disclosed (Pieterse, 2021).
17 August 2020	South Africa – Momentum Metropolitan	A third party unlawfully accessed a limited portion of data of a subsidiary of the group (Moyo, 2023).
14 March 2020	World Health Organization (WHO)	A malicious website was created, imitating the WHO internal email system, with the primary intention of stealing employee passwords (Chigada & Madzinga, 2021).
16 March 2020	United Kingdom – Hammersmith Medicines Research Group	Ransomware attacks resulted in the disruption of patient care and a halt in healthcare service provision (Goodwin, 2022).
22 March 2020	United States – Health and Human Services (HHS)	Ransomware attacks resulted in the publication of patients' personal details and a failed attempt to disable the network (Kiser & Maniam, 2021).

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South African healthcare institutions are increasingly becoming targets of coordinated cyberattacks such as ransomware, theft of personal health information, denial of service attacks and malware (Chuma & Ngoepe, 2022; Ngoepe & Marutha, 2021). Hospitals in South Africa are frequently targeted for two primary reasons: the absence of a robust regulatory framework governing personal health information and inherent vulnerabilities stemming from poor cybersecurity posture (Chuma & Ngoepe, 2022).

The ransomware attack in July 2020 at a major hospital in South Africa highlights the critical importance of incorporating cybersecurity learning (Burke et al., 2021). The incident's severe disruption of the hospital's operations for an extended period could have endangered patients' well-being and access to critical medical services. This ransomware attack emphasises the urgency for healthcare organisations to proactively enhance their cybersecurity learning capabilities. Healthcare institutions can better safeguard their essential systems and data by continually adapting and improving their cybersecurity responses, ensuring the uninterrupted delivery of life-saving healthcare services. Mitigating the risks posed by cyberthreats in the ever-evolving digital landscape becomes paramount in protecting patients' safety and well-being, making cybersecurity learning an indispensable aspect of healthcare management and operational resilience.

The enforcement of the Protection of Personal Information Act (POPIA) in South Africa has intensified the imperative for healthcare organisations to enhance their cybersecurity learning capabilities (Olofinbiyi, 2022; Sutherland, 2021; Townsend, 2022). Healthcare organisations face substantial pressure to adhere to data privacy legislation and enhance their cybersecurity learning efforts.

While substantial progress has been achieved in addressing cybersecurity challenges within the healthcare domain, most studies utilise existing cybersecurity frameworks (Akinsanya et al., 2019; Kruse et al., 2017; Thompson, 2017). However, these cybersecurity governance frameworks are inherently static and lack provisions for cybersecurity learning. Consequently, we propose a Dynamic Cybersecurity Learning Capabilities (DCLC) model to improve the agility of cybersecurity initiatives in a healthcare context.

3 THEORETICAL FOUNDATIONS

3.1 Dynamic cybersecurity capabilities

Teece et al. (1997) coined the term "dynamic capabilities" and defined dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competencies to adapt to rapidly changing environments. Eisenhardt and Martin (2000) extended this definition, depicting dynamic capabilities as the organisational processes that utilise resources, particularly those for integration, reconfiguration, acquisition, and release, to match and even create market change. In this vein, dynamic capabilities encompass firms' strategic and organisational routines to achieve new resource configurations as markets emerge, collide, split, evolve, and decline.

An alternative perspective, presented by Helfat et al. (2007), perceives dynamic capabilities as the ability of an organisation to create, extend, or modify its resource base deliberately. Recent research has distilled dynamic capabilities into three fundamental constructs: sensing (identifying opportunities and threats), seizing (orchestrating business design), and transforming (implementing a business model) (Daniel & Wilson, 2003; Zollo & Winter, 2002).

We expand the scope of the dynamic capabilities theory to cybersecurity, introducing the term *dynamic cybersecurity capabilities* (DCC) to describe our focus. Similarly, we adapt the fundamental elements of dynamic capabilities theory and introduce the terms *cybersecurity sensing* (CSn), *cybersecurity seizing* (CSz), and *cybersecurity transformation* (CT) to align with our specific emphasis on cybersecurity.

CSn pertains to continuously monitoring the internal and external healthcare environment, enabling healthcare organisations to identify potential cybersecurity threats and opportunities for enhanced defences. CSz involves adeptly orchestrating cybersecurity initiatives and designing refined defence mechanisms to capitalise on identified opportunities (Daniel & Wilson, 2003; Zollo & Winter, 2002). CT in healthcare refers to the capability to realign and reconfigure cybersecurity routines, processes, structures, and organisational culture (Easterby-Smith, 1997; Teece, 2018).

Healthcare institutions must foster a cybersecurity learning culture, encouraging continuous experimentation, innovation, and skill development to adapt to the dynamic cybersecurity landscape. Investing in employee training and development becomes a strategic imperative to nurture a talented workforce capable of contributing to the development and execution of dynamic capabilities in cybersecurity.

3.2 Cybersecurity learning

Organisational learning is a dynamic process wherein members of the organisation interact and exchange knowledge, leading to the creation of shared knowledge that exceeds the sum of individual knowledge (Curado, 2006). This continual learning process enables people to enhance their capabilities, fostering self-update, flexibility, agility, speed, and innovation within the organisation (Crossan & Berdrow, 2003). Organisational learning emerges as individuals interact, collaborate, and collectively find solutions to challenges (Easterby-Smith, 1997).

Encouraging knowledge sharing, lifelong learning, and fostering a culture of challenging the status quo are key aspects of promoting organisational learning (Curado, 2006; Wang & Ahmed, 2003). Organisations must establish processes that facilitate knowledge exchange among employees at all levels, encouraging them to learn and seek innovative approaches continuously (Visser, 2011). Additionally, learning from failure and incorporating feedback is vital to the improvement and growth of the organisation (Visser, 2011).

To align with our specific focus on cybersecurity, we customise organisational learning and introduce the term "cybersecurity learning" (CL). This term precisely encapsulates our emphasis on the dynamic learning processes related to cybersecurity practices and strategies.

Cybersecurity learning is crucial in the healthcare sector to safeguard patient data, maintain trust, comply with regulations, and effectively counter the ever-evolving cyberthreats. It is an essential aspect of modern healthcare management, protecting patients and healthcare organisations from the adverse effects of cyberattacks.

3.3 Cybersecurity inertia

Organisational inertia is an operational phenomenon in which an organisation sticks to its past practices to maintain stability (Ashok et al., 2021). Such inertia can hinder organisational learning, preventing the organisation from adequately responding to a turbulent external environment. If an organisation operates in a volatile environment, maintains the status quo over a long period, and fails to adapt to change promptly, that can be evidence of organisational inertia (Borkovich & Skovira, 2019; Renaud & Ophoff, 2019). Organisational inertia is associated with stable structures and processes that do not change over time (Hur et al., 2019; Yayla & Lei, 2020). Inertia manifests in different ways within organisations, including information suppression, excessive commitment to organisational structure, bureaucracy and rigid rules (Hur et al., 2019). Organisational inertia stifles organisational learning.

We refine the organisational inertia theory to better align with our research and introduce the term *cybersecurity inertia*. Our approach addresses the concept of organisational inertia within the cybersecurity context, providing a more focused lens for our investigation. Cybersecurity inertia results from the stickiness of traditional cybersecurity practices and routines (Borkovich & Skovira, 2019).

Healthcare institutions face significant challenges as they strive to accommodate the ever-evolving and expanding cybersecurity landscape within their organisation and the broader external context (Hur et al., 2019; Renaud & Ophoff, 2019). However, in many instances, healthcare organisations facing a widening threat landscape recognise the need for change but struggle to improve their defensive posture (Hur et al., 2019). Cybersecurity inertia often manifests as a resistance to adaptation, an excessive commitment to rigid structures, and the suppression of information (Ruiz-Mercader et al., 2006).

Next, we present a conceptual framework combining DCC, CL, and CI concepts. Through this synthesis, we theorised a dynamic cybersecurity learning capabilities (DCLC) model, the guiding framework for our case study analysis.

4 CONCEPTUAL FRAMEWORK

Figure 1 shows a direct link between DC and DCC (Besson & Rowe, 2012). Thus, CL helps build the capacity to perceive and accommodate external changes. Conversely, inadequate CL can lead to CI and rigid structures, hindering the development of DCLC (Ferreira et al., 2021).

Scholars have applied dynamic capabilities, organisational learning and inertia to business functional units such as information technology and cybersecurity (Mehra & Dhawan, 2003; Naseer et al., 2018; Ruiz-Mercader et al., 2006). In our study, we adopt dynamic capabilities,

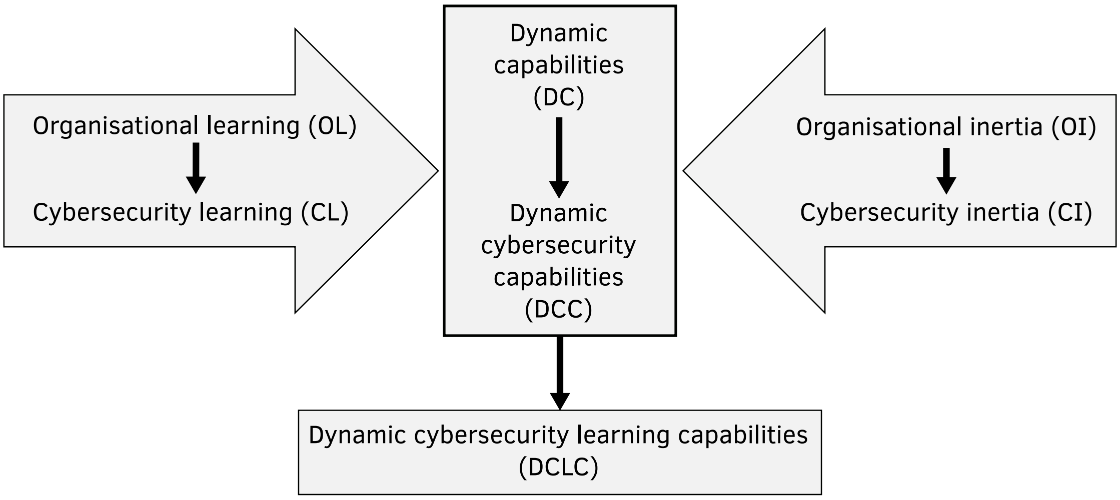

Figure 1: Conceptual framework

organisational learning, and organisational inertia concepts as a guiding framework to theorise a novel DCLC model. We aim to enhance the understanding of how dynamic cybersecurity learning can be incorporated into organisational practices to foster adaptive, responsive and resilient cybersecurity strategies.

5 METHODOLOGY

This section outlines the research methods employed in this study. Firstly, we provide a background of the case study and offer a rationale for selecting the specific case. Subsequently, we detail the data collection process utilised in this research. We present an overview of the data analysis approach employed to derive insights from the collected data. Finally, we outline principles that we followed to comply with research ethics.

5.1 Case description

We adopted an interpretive case study approach because it is suitable for investigating complex social contexts (Baškarada, 2014; Walsham, 1995; Yin, 2018). Our case study explores the cybersecurity practices at HSSP (pseudo-name), a healthcare software services provider. The study examines the inertial forces to dynamic cybersecurity learning capabilities at HSSP and offers solutions to overcome the inertia.

HSSP, a healthcare software service provider based in Johannesburg, South Africa, founded in 1999, offers software as a service solutions to medical practitioners and hospitals. Their platform includes billing, clinical, and bureau services, streamlining medical practices' workflows and improving revenue management. The solutions integrate with medical funders, providing automated benefit checks and real-time electronic claims processing. They also offer electronic medical record (EMR) and electronic health record (EHR) solutions, storing patient information and enabling electronic scripts, sick notes, and referrals. In response to the COVID-19 pandemic, HSSP developed a vaccine administration solution used by medical aid funders.

HSSP, a custodian of sensitive healthcare information, is potentially an attractive target for cybercriminals seeking valuable personal health information (PHI) (Appari & Johnson, 2010; Soomro et al., 2016). Consequently, HSSP should embrace robust information security practices that can guarantee the confidentiality, integrity, and availability (CIA) of the data entrusted to its care. Moreover, HSSP should exhibit resilience, adaptability, dynamism, agility, and responsiveness in the face of ever-evolving cybersecurity threats that persistently affect the healthcare sector. By fostering these capabilities, HSSP can proactively navigate the dynamic cybersecurity landscape, safeguard critical healthcare information, and preserve the continuity of its services.

HSSP places a significant emphasis on cybersecurity. The policy declaration within a cybersecurity document affirms cybersecurity as a focus area:

> *HSSP is committed to understanding and effectively managing risks related to Information Security to provide greater certainty and confidence for our stakeholders, employees, patients, partners, suppliers and the communities in which we operate. Finding the right balance between information security risk and business benefit enhances our business performance and minimises potential future exposures*
>
> [Information Security Policy, Chief Executive Officer, May 2022, p. 1]

5.2 Data collection

The researchers employed purposive sampling as their sampling method to select research participants deliberately and strategically. The data collection process encompassed both primary and secondary sources. Primary data was gathered through twenty-five interviews. All were conducted online via Google Meet as a precautionary measure in response to COVID-19 concerns. Each interview was digitally recorded and subsequently transcribed. The interview duration varied, ranging from 34 minutes to 67 minutes, with an average duration of 47 minutes.

The sample group of research subjects (Table 2) comprised external cybersecurity consultants who directly interacted with HSSP and technical teams serving specific customers. Diverse roles were represented among the research subjects, including Executives, Development Leads, Information Security Consultants, Product Specialists, Information Security Specialists, IT professionals, and finance professionals. To ensure the systematic collection of relevant information, we utilised an interview guide during the interviews.

Apart from conducting interviews, we also utilised document analysis as part of our data collection. This analysis encompassed various documents, including information security policies, strategy documents, business plans, roadmaps, budget reports, product documentation, meeting minutes, and content from the company's website. Document analysis was

Table 2: Research subjects

Department	**Role in organisation**	**# participants**
Cybersecurity Specialists	Included external cybersecurity consultants who provide cybersecurity services to HSSP and internal cybersecurity staff.	5
Product Support	Included product owners for the HSSP products, product support staff, and call centre.	6
IT Operations	Included IT service desk, user support and infrastructure support.	4
Other Shared Services	Included finance, human resources and administrative staff.	3
Software Developers	Included software development managers, leads and software engineers.	5
Integration Partners	Included IT and staff from integration partners.	2

used as a supplementary technique to complement, and validate and cross-reference the data we acquired through interviews.

5.3 Data analysis

For the thematic analysis, we followed the four-step guideline proposed by Green et al. (2007). Our study utilised a hybrid approach, combining deductive and inductive coding to develop themes (Fereday & Muir-Cochrane, 2006). Initially, we created a code template that included codes from the literature (Roberts et al., 2012). Initial codes were derived from key concepts from (DCC), (CL) and cybersecurity inertia (CI). Table 3 illustrates the key concepts that served as the foundation for our initial codes.

Table 3: Definition of key concepts

Key concept	**Definition**	**Theory**	**Example from case**
Cybersecurity flexibility	The ability of a firm to quickly and easily adapt its cybersecurity operations to capitalise on the external environment and proactively respond to cybersecurity threats that may affect the organisation's performance (Teece et al., 1997).	DCC	*"You know, we carry out tabletop exercises at least once a year. T-tops help us understand the potential threats we might face and explore various scenarios and permutations. By doing so, we get a better overview of our security risks and overall posture."*

[Continued …]

Table 3: […continued]

Key concept	Definition	Theory	Example from case
Cyber resource orchestration	The capacity of a firm to manage, coordinate and systematically combine its internal resources to position itself advantageously in the cyber environment (Helfat et al., 2007).	DCC	*"I don't think we can get a bigger team than what we currently have. However, we can leverage external consultants to provide backup support to our key team members. This approach should give us some breathing space and additional expertise without the need to hire more permanent security resources, which can be quite expensive."*
Cybersecurity anticipatory orientation	The ability of a firm to actively look for and respond to cybersecurity threats proactively. This is achieved by creating a culture of foresight, using various techniques to identify changes in the threat landscape, such as vulnerability scanning, penetration testing and secondary research (Teece, 2014; Teece et al., 1997).	DCC	*"Absolutely! I believe it's of utmost importance for HSSP (pseudo name) to understand and anticipate the actions of cybercriminals. Conducting vulnerability assessments and penetration tests at least annually can help us stay ahead of potential threats."*
Cybersecurity knowledge creation	Cybersecurity knowledge creation refers to creating, sharing, and storing cybersecurity knowledge within an organisation (Curado, 2006).	CL	*"… so there is need for continuous education and awareness of what's happening around us as far as system security is concerned. So I think that's very key for us as any organisation as HSSP to have those trainings, awareness continuously …"*
Cybersecurity memory	Cybersecurity memory is the process of retaining, sharing and leveraging cybersecurity information from past personal experiences within an organisation. It can be seen as a tool to enhance cyberthreat response within a company and allow for new opportunities (Wang & Ahmed, 2003).	CL	*"We need to continuously educate our users on information security issues. We need to educate users and carry out some random phishing assessments where we can identify users that potentially need additional training."*
Socio-techno inertia	Socio-technical inertia is the tendency of people and organisations to maintain the status quo when confronted with a new technology or process. This can include a reluctance to change, even when changes could offer significant benefits (Rowe et al., 2017).	CI	*"… for instance, we have some legacy applications that are not using the latest operating systems. It's not only up to the tech team to do it. It's also actually a business problem. So, we have to look at it from that perspective."*

[Continued …]

Table 3: [...continued]

Key concept	Definition	Theory	Example from case
Cybersecurity sensing	Refers to monitoring the external cybersecurity environment for possible opportunities and threats (Teece et al., 1997).	DCC	*"I think that as an organisation, we should do regular penetration testing of our systems so that we can identify loopholes before malicious hackers identify them. So, in other words, we should be proactive in identifying those loopholes."*
Cybersecurity seizing	This means the business must have the vision, insight and strategic foresight to identify and act upon cyberthreats (Teece et al., 1997).	DCC	*"Once we identify any vulnerabilities or weaknesses, we should be proactive and create a clear remediation plan before any incidents occur. This way, we can respond swiftly and effectively to any cyberthreats."*
Cybersecurity transforming	Refers to the ability to anticipate and adapt to changes in cyberthreats and to use resources and capabilities to shape and react to the cybersecurity environment (Teece et al., 1997).	DCC	*"We have started a process of migrating all our systems from on-premises to online, that is, to the cloud, which is a way of promoting high availability because you find that the cloud systems that we are using, some of them are in the US, some are in the UK and so forth. So it ensures high availability and allows us to recover when there is a disaster."*

The subsequent phase entailed validating the suitability of the initial codes by coding the documents and applying the deductive codes from the code template (Teece, 2014). The researcher meticulously analysed the interview transcripts line by line, resulting in the emergence of inductive codes when the deductive codes were insufficient in capturing meaning – these new insights led to the creation of new codes or extensions of existing ones (Rowe et al., 2017). The codes were consolidated into categories, where the relationships between the codes were examined to establish linkages and coherence. The final step encompassed identifying the overarching themes. ATLAS.ti and Microsoft Excel were used to code, categorise, and store themes.

5.4 Research ethics

We implemented multiple measures to adhere to research ethics. Firstly, the researcher obtained permission from HSSP's senior management. The researchers obtained permission to access relevant cybersecurity documents and interview key cybersecurity staff members. They also ensured strict compliance with privacy and confidentiality ethical guidelines at all times. Secondly, the University's ethics committee reviewed and approved the interview guide. Additionally, explicit consent was obtained from all participants, ensuring voluntary participation and respecting their autonomy. Furthermore, anonymity was preserved, protecting participants' identities. Further, transparency was maintained through overt observations, where participants were informed in advance, and the study's purpose was communicated. These measures upheld ethical guidelines and safeguarded participants' rights and welfare, fostering an environment of trust and credibility (Soomro et al., 2016).

6 DYNAMIC CYBERSECURITY LEARNING DRIVERS AND CYBERSECURITY INERTIAL FORCES

We identified and analysed the cybersecurity inertia drivers, which are the forces that resist changes to the status quo in cybersecurity practices. These inertia drivers significantly hinder the development of dynamic cybersecurity learning capabilities (DCLC) within HSSP. To foster effective DCLC, addressing and mitigating these cybersecurity inertia drivers is imperative.

We also explored the dynamic cybersecurity learning drivers that push HSSP towards adopting and embracing dynamic cybersecurity learning capabilities. These drivers challenge the conventional cybersecurity norms and encourage organisations to seek adaptive and innovative solutions to overcome the inertia that impedes the implementation of dynamic cybersecurity learning capabilities. By understanding and leveraging these dynamic cybersecurity learning drivers, HSSP can actively drive transformative changes in its cybersecurity strategies and practices.

As dynamic cybersecurity capabilities strengthen, they weaken cybersecurity inertia (Chiu et al., 2016; Rowe et al., 2017). Dynamic cybersecurity capabilities collectively reduce the inertia caused by the socio-technological factors that impede organisational change. Similarly, we posit that dynamic cybersecurity capabilities are pivotal in weakening cybersecurity inertia.

Figure 2 reveals the antagonistic nature of two main factors influencing DCLC (Dynamic Cybersecurity Learning Capabilities): the dynamic cybersecurity learning drivers, which challenge the status quo, and the cybersecurity inertia drivers, which strive to maintain the current state. In Sections 7 and 8, we explore these antagonistic factors in depth.

7 CYBERSECURITY INERTIA DRIVERS

Cybersecurity inertia drivers encompass the factors that hinder cybersecurity learning within HSSP. These drivers create resistance to change, hamper adaptive cybersecurity practices, and elevate the risk of cyberattacks.

7.1 Strategic level inertia

Strategic inertia is the tendency of senior and middle-level management to remain with the status quo and resistance to strategic renewal outside the frame of current strategies (Hopkins et al., 2013). Senior management plays a critical role in the development of DCLC. Senior

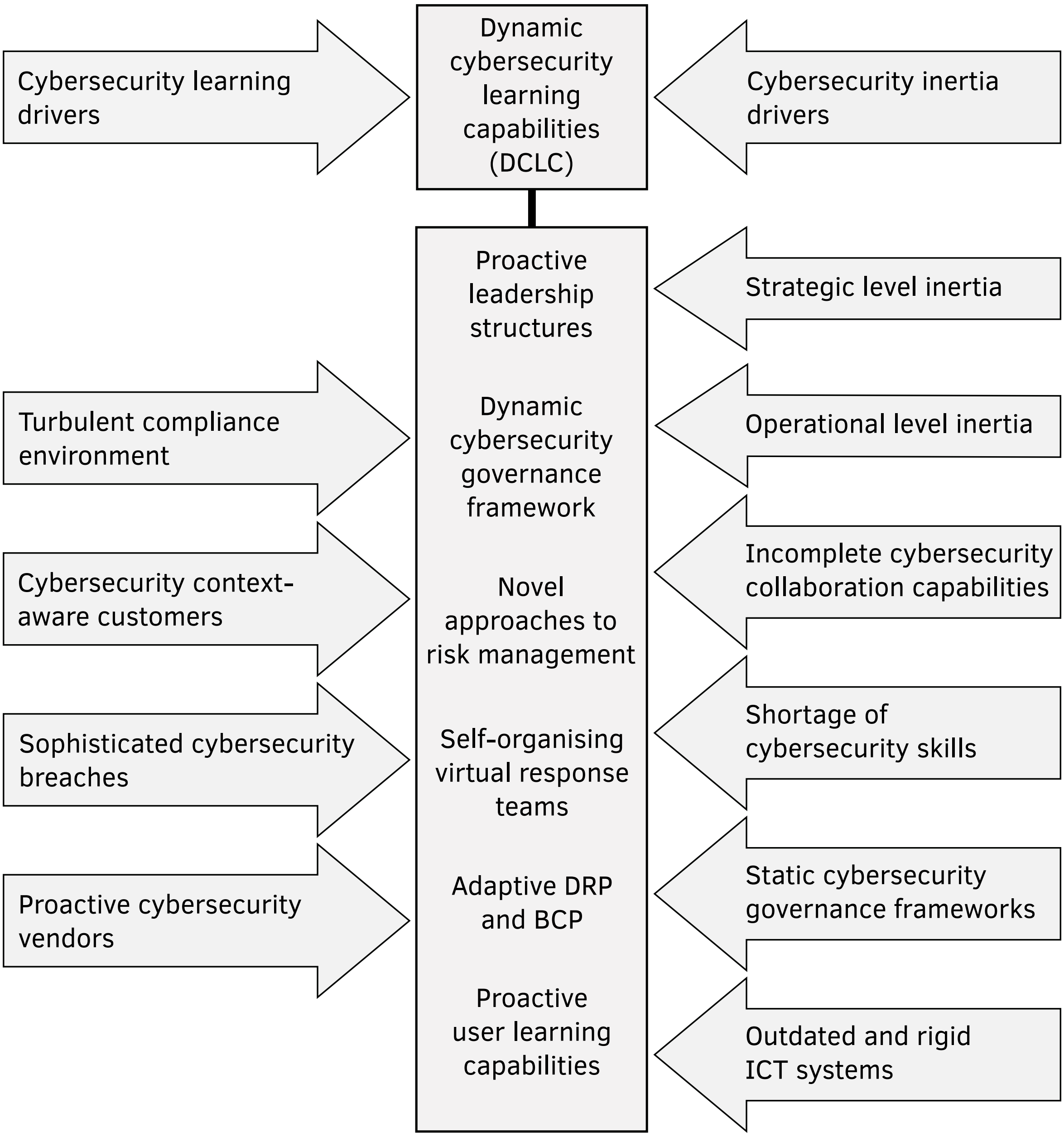

Figure 2: Dynamic cybersecurity learning drivers, cybersecurity inertial forces and DCLCs.

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management is responsible for setting the tone and creating agile structures that create an enabling DCLC environment.

A cybersecurity expert argued that there is a gap between technical people and senior management. Cybersecurity experts mentioned,

> *When it comes to security, in most cases, executives and technical people are not always on the same wavelength. There is a need for someone to bridge this gap between top management and specialists. I think it would be beneficial to have an executive specifically responsible for security, a CISO or maybe if it is not possible to employ a CISO, there should be a security steering committee of some sort.*

Strategic level inertia contributes to cybersecurity inertia. Senior management sets the broad strategy for the organisation, including cybersecurity.

7.2 Incomplete cybersecurity collaboration capabilities

HSSP employs a shared services model for service departments such as information technology and information security. An executive stated,

> *We adopted the shared service model to allow the business units to focus on their core offering and reduce non-core services duplication.*

The evidence gathered from the interviews suggests collaboration gaps as teams focus on their core competencies. The cybersecurity function is not involved in product design and evolution. When asked how cybersecurity is embedded in software development, a software development lead said,

> *Okay, as developers in my department, we mainly focus on ensuring that we get the functionality right. I think more can be done when it comes to security. Maybe we can have someone who is specifically assigned to security issues when it comes to development.*

By cultivating a collaborative environment, HSSP can enhance its ability to detect cybersecurity threats proactively and devise cutting-edge countermeasures to combat them effectively.

7.3 Shortage of cybersecurity skills

The interviews showed that cybersecurity personnel prefer to work in the banking, telecommunications and financial service sectors. A former information security specialist said,

> *I left after three years mainly because I wanted financial and career growth. Remember, security is based on what you are trying to protect, so telecommunications are bigger than HSSP, so they obviously have a bigger budget to spend on security. I also realised that I had reached the ceiling in terms of growth as a security specialist. I was occupying the highest position available.*

There is a global shortage of skilled cybersecurity professionals, and the estimated global shortfall of cybersecurity skills is 6 million (Burrell, 2018; Lewis & Crumpler, 2019). The global shortage of cybersecurity skills and relatively lower remuneration make it difficult for the healthcare sector to attract and retain skilled cybersecurity professionals. A lack of cybersecurity skills makes it difficult for healthcare firms to cope with unpredictable cybersecurity threats. To address cybersecurity skills needs, organisations should strive to create an approach to cybersecurity that is actively monitored and regularly updated to meet the changing threats.

7.4 Static cybersecurity governance frameworks

Cybersecurity frameworks (CSF) help policymakers to define cybersecurity strategies using a policy template. CSFs allow management to cascade the cybersecurity strategy in clear, non-ambiguous statements (Azmi et al., 2018). CSF provide a basis for the implementation of cybersecurity strategy to be tracked and measured (Campos et al., 2016).

An IT executive said,

> *We follow the best practices in everything we do, including cybersecurity. Our systems and processes are mature, and we are using top-end technology. Before we disposed Subsidiary-Z (alias) we had PCI audits at least once a year, so our systems and processes are tried and tested.*

CSFs and best practices offer stability and predictability. However, CSFs are too rigid and may fail to give protection against adventurous cyberattackers developing exploits rapidly. There is a need for a dynamic framework which adapts to the ever-changing threat landscape.

7.5 Outdated ICT systems

A senior manager at HSSP mentioned,

> *I am sure you will also find some areas in which we are not doing right; for instance, we have some legacy applications that are not using the latest operating systems. It's not only up to the tech team to do it. It's also actually a business problem. So we have to look at it from that perspective.*

It was evident from the case that some key clients used legacy and vulnerable applications that could not be made obsolete for genuine business reasons. Legacy applications present significant security risks and vulnerabilities. Legacy systems may not support the latest encryption standards and modern security features like multifactor authentication, role-based access and single sign-on (Abraham et al., 2019). The dissemination of security vulnerabilities through blogs and journals inadvertently exacerbates the challenges posed by legacy applications. Although this documentation is created with the noble aim of keeping the security community informed and updated, it unintentionally provides hackers with novel information that can be used to craft exploits for cybersecurity attacks (Langer et al., 2016).

7.6 Operational level inertia

Operational level inertia refers to the phenomenon in which established routines limit the ability to introduce new processes and changes to the daily operations of an organisation. Operational level inertia often results from limited resources, outdated processes and manual processes that are hard to change.

Cybersecurity scholars agree that employees are the weakest link in the cybersecurity stack (Evans et al., 2019; Nobles, 2018; Streeter, 2015). Operational level inertia in cybersecurity manifests itself in users sticking to insecure information security practices, which puts the organisation at risk of successful social engineering attacks. Changing the insecure practices requires significant time, energy, information security awareness training and reinforcement.

A developer admitted not attending any information security awareness training since joining HSSP.

> *I lead a team of developers, and I am quite sure that they will be able to recognise information security threats. I don't remember attending any scheduled information security awareness training. Still, I think it would be helpful to have such training just to refresh knowledge as well as to help us keep such issues at the top of our minds.*

Information security awareness training reinforces cyber hygiene principles and helps employees proactively recognise and respond to user-side cyberattacks.

8 CYBERSECURITY LEARNING FORCES

In this section, we discuss the main forces for change. The forces or environmental influence that put pressure on organisations to adapt to changes in the cybersecurity environment. Cybersecurity learning forces pressure organisations to embed knowledge creation, retention and modification.

8.1 Turbulent compliance environment

Most participants agreed that the Protection of Personal Information Act (POPI) was a wake-up call for executives and senior management. One senior manager said,

> *I think we will be doing POPI assessments. In South Africa, I think we are one of the early adopters of POPI and really making sure that we are compliant. I think we take it quite seriously.*

The enactment of POPI came with a threat of regulatory fines and personal liability for directors and senior management. The fear of regulatory penalties and being in the newspaper headlines for the wrong reasons has seriously induced senior management to focus more on developing dynamic cybersecurity learning capabilities.

8.2 Sophisticated cybersecurity breaches

There were some highly publicised high-profile cybersecurity breaches in the healthcare sector in South Africa. Life Healthcare hospital group in South Africa was targeted by ransomware attacks that stopped all IT systems in July 2020. At the time of the breach, the Group CEO posted on the Life Healthcare website,

> *We are deeply disappointed and saddened that criminals would attack our facilities during such a time when we are all working tirelessly and collectively to fight the COVID-19 pandemic.*

Cybersecurity breaches have shifted focus among IT and cybersecurity professionals. The cybersecurity breaches in the healthcare sector served as a warning to management. One application engineer mentioned,

> *I am not aware of any cybersecurity incident that has affected HSSP since I started working here. The only incident I remember is when we reimaged all the servers linked to firm Z (pseudo name) following an incident there.*

Cybersecurity breaches at key partners can have significant implications for HSSP.

8.3 Cybersecurity context-aware customers

Organisations the world over are increasingly becoming more conscious of their personal information. Organisations are increasingly demanding that their partners put comprehensive cybersecurity policies in place to avoid data breaches. Customers of Nedbank, a South African bank, were compromised through a third-party service provider, Computer Facilities (Pty) Ltd. The Nedbank compromise exposed the personal information of over 1.7 million customers (Roos, 2023).

The potential loss of data through third parties has resulted in partners of HSSP requesting additional cybersecurity controls. One cybersecurity expert mentioned that some integration partners are asking HSSP to complete annual cybersecurity questionnaires. According to the experts, HSSP's partners also demand cybersecurity assessment reports such as vulnerability analysis and penetration testing reports. A cybersecurity professional stated,

> *Of late, we have been receiving requests to fill in some forms with questions regarding our cybersecurity posture, vulnerability scans, penetration test, encryption and so on. I can say that this started in the last year or two. We have not yet started doing this to our integration partners. I think we may need to look at ourselves in the mirror and ask some questions: are we doing things right? Are we lagging? These are real issues that need genuine answers.*

8.4 Proactive cybersecurity vendors

Vendors of cybersecurity-related solutions trying to create awareness of their products publicise cybersecurity breaches and provide information on how their solutions provide defences against cybersecurity breaches. Vendors of cybersecurity solutions are creating awareness of cybersecurity risks.

A cybersecurity expert at HSSP mentioned that members of the strategic leadership team are invited to the annual cybersecurity expo by Trend Micro, one of the vendors of cybersecurity solutions. The cybersecurity conference gives a platform for management to understand the key cybersecurity risks and the defences that can be put in place to defend against them. A cybersecurity expert mentioned,

> *I know of Amazon, Microsoft, Fortinet, to name a few. They showcase their solutions which can help us to solve some of our day-to-day challenges, I think the benefits of these exhibitions are two-fold really, first, they help us to introspect and identify some of our potential pain points, and obviously, they also help us to find solutions to our problems. It's like a doctor asking about your symptoms and also prescribing medication.*

9 DYNAMIC CYBERSECURITY LEARNING CAPABILITIES

After identifying cybersecurity inertia as a significant obstacle to DCLC, we propose interventions to overcome this challenge. These interventions aim to assist in the development of DCLC, ensuring a more agile and resilient cybersecurity approach at HSSP. Our argument emphasises that effectively managing cybersecurity inertia will lead to notable improvements in DCLC. HSSP can enhance its ability to adapt and respond proactively to the evolving cyberthreat landscape by addressing and mitigating cybersecurity inertia.

9.1 Proactive leadership structures

Executive management is responsible for setting the tone and disseminating information regarding the organisation's risk appetite. The board of directors (BoD) is ultimately responsible and accountable for cybersecurity (von Solms & von Solms, 2018). The BoD may delegate responsibility for cybersecurity to executive management.

To improve the involvement of senior management in cybersecurity, we are proposing proactive leadership structures to guide the development and implementation of DCLC. Proactive leadership structures include an IT security steering committee with members drawn from leaders of all the important facets of the business. IT security steering committees are recommended by scholars (Alkhaldi et al., 2017; Parekh, 2009) and the cybersecurity practitioners we interviewed. An IT security steering committee improves collaboration and dissemination of cybersecurity-related, improving the responsiveness against cyberthreats.

9.2 Dynamic cybersecurity governance framework

The cybersecurity governance framework provides an organisation with an all-encompassing, holistic plan for information security (Da Veiga & Eloff, 2007). It combines technical, procedural, and people-oriented components to reduce cybersecurity risk to an acceptable level (Ohki et al., 2009). Management and executives can use a cybersecurity governance framework to plan, track, and control the cybersecurity function (Schlienger & Teufel, 2003). Without a cybersecurity framework, it is difficult to assess the performance of the cybersecurity function.

All the cybersecurity professionals interviewed concurred that a cybersecurity governance framework is necessary for managing the cybersecurity function. Cybersecurity frameworks are static and are updated only after preset intervals. We propose the implementation of a dynamic cybersecurity governance, which builds on continuous sensing of the environment, mobilising internal resources and renewing cybersecurity capabilities.

9.3 Novel risk management approaches

Cybersecurity experts recommended implementing novel approaches to risk management, such as regular vulnerability assessments, penetration tests, security assessments, and cyber insurance (Siegel et al., 2002). Innovative insurance solutions, such as cyber insurance, are a fallback plan, acting as a last resort if other risk management approaches prove insufficient (Woods & Simpson, 2017). Leveraging our dynamic cybersecurity learning capabilities approach, HSSP can swiftly detect and respond to cyberthreats, minimising the risks associated with cyber-attacks and safeguarding their valuable information and reputation.

9.4 Self-organising virtual response teams

PARTICIPANT 8 said,

> *I think maybe if we are to have an application security specialist, that will be great because that person will now have the time to look specifically at security issues associated or which are around the development of software and then another thing that we could also do is maybe to adopt DevSecOps that is to embed security right from the start to ensure that at that moment we are gathering requirements, we also embed security up to the point where we are deploying a system. I think that will give us more secure systems.*

Self-organising teams such as DevSecOps can be used in cybersecurity for greater response and resilience to cyberthreats (Prates et al., 2019). Self-organising teams are composed of highly skilled individuals who can self-manage, adapt and learn new tasks whilst being empowered by the team as a whole (Myrbakken & Colomo-Palacios, 2017). Such teams behave as autonomous units, making decisions collectively and without the need for direct manager input. In this context, the perceived benefits of self-organising teams include reduced decision-making times, greater problem-solving capabilities, a stronger focus on creative solutions and improved organisational performance.

DevSecOps brings together development security and operations. DevSecOps incorporates modern security practices in DevOps's dynamic and agile world (Prates et al., 2019). The DevSecOps model improves the coordination between security and development and ensures security is built into systems design.

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9.5 Proactive user learning capabilities

Numerous studies have shown that information security awareness training and education reduce users' susceptibility to phishing attempts (Alsharnouby et al., 2015; Kumaraguru et al., 2008; Mayhorn & Nyeste, 2012). Most cybersecurity breaches are a result of unintentional mistakes by users. Information security awareness training is necessary to reinforce cyber hygiene principles.

The study revealed that HSSP's information security education interventions are inadequate. The cybersecurity practitioners interviewed emphasised the importance of information security awareness training. Most cybersecurity practitioners recommended that HSSP invest in online information security awareness platforms. A participant recommended regular penetration tests targeting users to measure information security awareness's effectiveness and identify training needs.

9.6 Adaptive disaster recovery and business continuity planning

The existing business continuity plans (BCP) and disaster recovery plans (DRP) need to be tested regularly to ensure the plans remain effective and relevant (Budiman et al., 2020). From the document review, we deduced that the existing plans had not been subjected to routine testing. We highly recommend conducting tests of business continuity plans at least once a year to prevent disruptions in the event of significant cybersecurity breaches (Budiman et al., 2020). Disaster recovery plan testing is important for two primary reasons: It helps determine whether the existing plan is relevant, complete, and adequate. It helps team members know what to do in a disaster (Cerullo & Cerullo, 2004).

10 DISCUSSION

This study makes several theoretical contributions. The study extends the dynamic capabilities theory (Helfat et al., 2007; Teece et al., 1997; Zollo & Winter, 2002) by introducing a novel dynamic capability, namely dynamic cybersecurity learning capabilities. The study integrates the concepts from dynamic capabilities theory with organisational learning and organisational inertia. We identified how socio-technical inertia can impede the development of DCLC. Organisational learning and organisational inertia theories provide a way to understand the inertial forces impeding dynamic cybersecurity learning. The theories provide a novel understanding of the inertial forces impeding the development of cybersecurity capabilities. Although organisational learning and inertia theories were initially formulated to offer insights at the corporate strategic level (Helfat et al., 2007; Teece et al., 1997), we contend these theories can be adapted and applied to cybersecurity.

This study offers valuable insights for practitioners looking to enhance cybersecurity within their healthcare software service firms. Practitioners often rely on static cybersecurity frameworks such as NIST CSF, ISO 27000, and CIS 20 (Frumento, 2019; Ibrahim et al., 2018).

However, this research goes a step further by expanding the capabilities of these existing frameworks, making them more agile and adaptable to evolving threats.

Additionally, traditional practitioner frameworks typically provide broad recommendations suitable for various organisations, irrespective of their specific contexts. In contrast, our proposed DCLC (Dynamic Cybersecurity Learning Capabilities) model considers the unique context of a healthcare software service firm. By gathering relevant data, we identified the inertial forces hindering the development of DCLC and designed a tailored model to address these challenges effectively. The context-aware approach of our DCLC model aims to optimise cybersecurity measures, enabling practitioners to bolster their organisation's resilience against cyberthreats within the healthcare domain.

Prior research has shown that most cybersecurity breaches result from human error (Evans et al., 2019; Nobles, 2018; Streeter, 2015), and deliberate measures should be taken in employee and management learning. Employees must be continuously reminded of how to prevent, detect, respond to, and recover from cyberattacks. Management should set the tone and provide leadership in developing dynamic cybersecurity learning capabilities. This study encourages practitioners to challenge the status quo and look for ways to create, disseminate, modify and retain new cybersecurity knowledge on an ongoing basis. Practitioners are urged to sense the environment continuously, seize opportunities and transform the organisation's cybersecurity function.

Our study is not a panacea to cybersecurity challenges at HSSP. Our proposed solutions are neither exhaustive nor prescriptive. The proposed solutions should be tested at the HSSP to have an opinion on their efficacy. This study cannot be replicated at other healthcare software service firms; independent studies should be performed.

Future research should test the effectiveness of the proposed initiatives at HSSP. Without testing the initiatives, they remain propositions. Future research could also test the applicability of the findings to other healthcare settings. The theoretically grounded dynamic cybersecurity learning framework provides novel approaches to managing ever-changing cybersecurity threats. Our DCLC model differs from existing studies because it fuses concepts from practitioner-centric cybersecurity frameworks with theoretical aspects from dynamic capabilities, organisational learning and organisational inertia.

11 CONCLUSIONS

In conclusion, this case study pinpointed the inertial forces hindering dynamic cybersecurity learning capabilities within a healthcare software services firm. By conducting semi-structured interviews with experts and analysing corporate documents, we gained valuable insights from these individuals and the existing records of the company. Through thematic analysis, the study uncovered two crucial aspects: the organisational inertia forces that maintain the status quo and hinder cybersecurity learning and the cybersecurity learning forces that drive organisations to proactively adapt to dynamic changes in the cybersecurity landscape by acquiring, modifying, and retaining knowledge.

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Identifying these contrasting forces sheds light on the pivotal interplay between organisational inertia and cybersecurity learning, underscoring their significant impact on shaping cybersecurity learning within healthcare software as a service firm. Moreover, the study proposes dynamic cybersecurity capabilities as a plausible solution to counteract the inhibiting effects of organisational inertia.

By cultivating dynamic cybersecurity capabilities, HSSP can effectively overcome the barriers that impede reinvention and fortification, enhancing its cybersecurity posture in the face of persistent threats. The research emphasises the importance of adaptability and continuous learning in fostering a robust and resilient cybersecurity approach for healthcare software services firms.

Pursuing Dynamic Cybersecurity Learning Capabilities (DCLC) represents a vital and promising research agenda for cybersecurity scholars, extending beyond the healthcare domain to encompass other critical sectors. By harnessing DCLC, the healthcare sector and other industries could significantly enhance their responsiveness to multifaceted cyberattacks. We believe that adopting the proposed DCLC framework will better enable healthcare organizations to continually adapt, learn, and evolve in response to rapidly emerging cyberthreats. This proactive approach will also help healthcare organizations to strengthen their defences and overcome strategic and operational inertial forces. Finally, we hope that researchers will further develop the dynamic learning capability perspective to advance cybersecurity knowledge, thereby bolstering organizational resilience in the face of rapidly evolving cyberthreats.

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Research Article

Sensemaking and the Potential Future-focused Curriculum for Society 5.0 Knowledge Managers: A South African Perspective

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ABSTRACT
When "quality being everyone's business" coincides with the reality of a disruptive work environment, critical self-evaluation becomes an essential tool to ensure accountability. Academics who design curricula and their tuition offering have a certain degree of freedom in what and how they teach. However, academics need to be consciously discerning, yet inclusive, about the voices that should speak into curriculum design. This study operates from the principle of co-creation in curriculum design and acknowledges the multiplicity of relevant voices that speak into curriculum design. These voices are influenced by the past, present, and possibilities of the potential future. To remain relevant in the imagined future, this research identified the co-creators and curriculum design partners for the multidisciplinary field of knowledge management. The curricula of three related academic departments were analysed to determine knowledge management tuition linkages. These curricula were then compared with the Skills Framework for the Information Age (SFIA) level descriptors. Following on from this desktop analysis, Sensemaker®, a distributed digital ethnographic methodology was piloted that will be used to collect micro-narratives from emergent curriculum co-creators. This article identifies gaps in current curricula, expresses expectations for future possibilities and highlights potential niche opportunities for knowledge management curriculum design.

Keywords Knowledge manager's capabilities, Society 5.0, disruptive technologies, Skills Framework for the Information Age, knowledge management curriculum

Categories • **Knowledge management ∼ Curriculum and skills competency**

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1 INTRODUCTION

Reading material about the fourth industrial revolution (4IR) the pervasive sentiment remains to be the fact that change is inevitable, at a rate never experienced before and at a scale, scope and complexity that humankind is yet to be exposed to. The future has always been uncertain, but speculation about our readiness for the disruptive and complex potential future has created anxiety among students that was last observed when the World Wide Web would have destroyed newspapers and the paper-based society in 1992. While research and development have been a constant in academic circles, research institutes and the industry at large, the most recent hype around artificial intelligence and the dangers associated with it reached mainstream media at the beginning of 2023 after ChatGPT was launched in late 2022.

In a capstone module taught to third-year students the number of queries about their readiness for work placement, their skill level and what work they can do with the degree they are about to earn escalated remarkably. Perhaps this observed insecurity of soon-to-be graduates can be ascribed to several influences of which the rapid changes in technology are merely one. Students express their concerns about being replaced by technology as they simultaneously navigate their way through studying during global lockdowns in online and hybrid modes, developing valuable experiences in transitioning almost seamlessly from face-to-face situations onto online platforms. During one-on-one conversations, the struggle they have to manage alternative solutions to pursue tasks through continuous load-shedding schedules speaks of resilience that will bode well during uncertain times in the future. These mentioned observations, historical and current realities along with anecdotal records gave rise to the guiding question for this research, namely:

> *What should be included in a curriculum to prepare potential future-focussed knowledge managers?*

While qualifications and certifications are generally the output of curriculum development and design endeavours, these form just a small part of all that is involved in preparing a student studying towards a qualification which could get them entry into a field such as knowledge management. The observations mentioned above refer to critical soft skills that can only be developed through lived experience. According to Mabe and Bwalya (2022), soft skills and competencies are critical enablers necessary to harness the possibilities that the 4IR would offer. Within the uncertainty of the 4IR, Schwab (2016) warns that the response to it must be integrated and comprehensive involving all stakeholders, much aligned with the human-centred approach that Society 5.0 advocates.

Smuts et al. (2022) distinguish between the 4IR and Society 5.0, regarding the 4IR primarily as the generation of knowledge and intelligence achieved by humans with the support of technology, while Society 5.0 focuses on knowledge and intelligence generation through machines and artificial intelligence in service of people. While the following prediction of the uncertain future by Gerber et al. (2021) will most likely turn out to be true, it also inspires the question of how the generation that is supposed to navigate this future should be skilled and what curriculum should be developed to support them in building the required competency.

> *Nobody knows with certainty what new technologies will emerge, what new industries will materialise and what skills will be in high demand. What we do know is that the future will be radically different from the work environment today, and the pace of change will be faster than anyone expects (Gerber et al., 2021).*

So, if Society 5.0 is about service to people and aims to bring human concerns back into how we think about technological advancement and human-machine interfaces (Gerber et al., 2021), then the human concerns and expectations should receive attention when designing the curriculum that needs to equip the Society 5.0 human workforce. Curriculum design and co-creation received rising interest in research and practice with students as partners and co-created learning and teaching (Bovill, 2020), recognising the student adopting four possible roles in this process, namely a representative, consultant, co-researcher, and pedagogical co-designer (Bovill, 2020). In keeping with Schwab's (2016) recommendation of involving all stakeholders in responding to the 4IR, the other stakeholders in co-creating the curriculum would be industry partners that generally employ the university graduates and the practitioner as a partner from the discipline's association or society perspective, not only in a national capacity but also from a global society or association perspective.

Academic staff in their capacity as researchers and from their roles to teach and learn have a certain degree of freedom in what and how concepts and content is brought together within a discipline. However, the expectations from the above-mentioned partners in the process need to be acknowledged within this freedom. In this study, co-created curriculum development and design is informed by the expectations expressed by the discipline as an institution, the expressed expectations of the world of work for whom graduates are trained, the students' expectations and aspirations as well as the experiences of the academic as a researcher and an educator. The students who expressed their expectations and aspirations form part of a bachelor's degree in which they can potentially pursue KM as a career choice. These KM-linked partners are challenged throughout this research to dig into their past experiences, probe the present curriculum and predict the skills and capability requirements of the knowledge managers of the future. The objectives of this research were to:

- Identify knowledge management skills and competencies as expected by the industry and business practitioners.
- Assess current curriculum offerings and explore curriculum linkages for the multidisciplinary discipline of knowledge management.
- Pilot a distributed digital ethnographic methodology that can be used to collect micro-narratives from all relevant curriculum co-creators.

In addressing the first objective the knowledge management skills and competencies as expressed by industry and business practitioners need to be identified.

2 KNOWLEDGE MANAGEMENT SKILLS

Ehlers and Kellermann (2019) collected data between 2015 and 2019 on the expectations of competence and skills for future learning in Higher Education. They define future skills as the "ability to act successfully on a complex problem in a future unknown context of action", referring to an "individual's disposition to act in a self-organised way, visible to the outside as performance" (Ehlers & Kellermann, 2019). They classify future skills into dimensions and skills profiles. The subjective dimension relates to personal abilities to learn, adapt and develop to improve work opportunities, shape working environments and cope with future challenges. The first seven of sixteen skills profiles were identified in the subjective dimension namely, autonomy, self-initiative, self-management, need/motivation for achievement, personal agility, autonomous learning competence and self-efficacy. The object dimension refers to an individual's ability to act self-organised with an object, task or subject matter issue. Five of the sixteen skills profiles reside in this dimension, agility, creativity, tolerance for ambiguity, digital literacy and the ability to reflect. The social world dimension refers to the individual's ability to act self-organised concerning the social environment, society and the organisational environment. The remaining four skills profiles associated with this dimension are sensemaking, future mindset, cooperation skills and communication competence. Sensemaking is a term that was coined by Dervin (1983) to study how people construct information needs and use information to bridge the cognitive gap. Sensemaking has been studied extensively in the field of KM (Dervin, 1992; Dervin, 1983, 1996; Klein et al., 2006; Pirolli & Russell, 2011; Snowden et al., 2021; Snowden, 2005; Weick et al., 2005).

While Ehlers and Kellermann (2019) take a broader approach beyond digital skills demands, Rhem (2017) identifies specific knowledge management (KM) roles, responsibilities and core competencies that are essential for the success of a KM project or programme. His list of roles is not exhaustive but includes Chief Knowledge Officer (CKO), KM Program Manager, KM Project Manager, KM Director, Operations KM Director, KM Author, KM Lead, KM Liaison, KM Specialist, KM System Administrator, Knowledge Engineer, Knowledge Architect, KM Writer, Knowledge Manager, and KM Analyst. Rhem (2017) acknowledges that KM has both soft competencies and hard competencies and identifies KM responsibilities as KM principles and foundation, KM strategy, KM leaders and champions, KM culture, communities of practice/knowledge sharing and transfer, content management, metrics, processes, KM technology systems and tools, and KM governance. However, from this list, some "responsibilities" can better be described as roles (KM leaders and champions) and others could rather be described as tools (KM technology systems and tools) or methodologies (communities of practice). Rhem (2017) also recognises that a distinction can be made between soft skills and hard skills.

Mabe and Bwalya (2022) using a systematic literature review followed by a Delphi technique specifically looking at South African data, identified the critical soft skills required for information and KM practitioners in the 4IR. They define soft skills as a combination of mental and meta-cognitive skills, interpersonal, cerebral and applied skills (Mabe & Bwalya, 2022). (Table 1) summarises a list of the 49 soft skills that Mabe and Bwalya (2022) regarded as necessary to maintain a competitive advantage in the 4IR. The list is presented in alphabetical order rather than any other logical categorisation.

Table 1: Soft skills from the systematic literature review (adapted from Mabe and Bwalya (2022))

Adaptability	Analytical skills	Assertiveness	Attentiveness	Behavioural skills	Capacity for lifelong learning	**Collaboration skills**
Commitment	Communication skills	Conceptualising skills	Confidence	Conflict resolution	Courtesy	Creativity
Critical thinking	Cultural awareness	Decision-making skills	Digital literacy	**Emotional intelligence**	Empathy	Entrepreneurship
Ethical skills	**Flexibility**	Foreign language proficiency	Good attitude	Good customer service	Good judgement	Handling uncertainty
Human management	Independence	Organisational skills	Prioritisation	Proactivity	Problem-solving	Professionalism
Quick information sharing	Reliability	Resilience	Resource management	Responsibility	Self-initiative	Social skills
Teamwork	**Thinking out of the box**	Time management	Transversal skills	Trust	Versatility	Work ethic

The Delphi technique in Mabe and Bwalya's (2022) study reached a consensus on 17 soft skills. The soft skills from the Delphi technique that were also identified in the systematic review are printed in **bold** in the list that follows and in Table 1.

Mabe and Bwalya (2022) identified these as:

1. leadership
2. **adaptability**
3. flexibility
4. **emotional intelligence**
5. honesty
6. integrity
7. **collaboration skills**
8. active learning
9. willingness to learn
10. **critical thinking**
11. **ethical** awareness for the use of data and big data

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12. innovation (perhaps similar to **thinking out of the box**)
13. planning skills
14. data collection and analysis
15. the ability to find, access, evaluate and transform data into information
16. the ability to use new information tools
17. being familiar with industry trends in big data systems

Perhaps those skills listed as 14–17 are not truly soft skills but rather technical competency. Ironically the skills identified by Ehlers and Kellermann (2019) and those identified by Mabe and Bwalya (2022) (excluding 14–17) are representative of skills that are developed from birth and are taught through life experiences and social interactions, such as group work, rather than through a designed curriculum. The challenge for any institution of learning is to create opportunities in the curriculum for these soft skills to be developed through learning environments, assessment opportunities, projects, and tasks.

A 2022 draft document on Knowledge Management Competency Framework (KMSA, 2022) suggests that knowledge managers should develop behavioural, core and technical competencies aligned to the ISO30401 standard. In this draft framework (KMSA, 2022), behavioural competencies are those previously described in this paper as soft skills that are applicable across occupational levels and roles. Core competencies are described to be foundational and unique to KM and correlate somewhat with the KM responsibilities described by Rhem (2017), but also include KM activities such as conducting a knowledge audit. Technical competency is described in this draft framework as "functional and technical competencies that provide for different levels of complexity described in accordance with the occupational levels" (KMSA, 2022).

The Skills Framework for the Information Age (SFIA), currently in its 8th version is a globally consulted and collaborated framework that oversees the production, design and use of skills and competencies required by professionals who design, develop and implement, manage and protect data and technology in the digital world (S.F.I.A., 2023). SFIA is therefore already geared towards establishing level descriptors, competencies and skills for occupations and roles that drive the frontiers of the information age. SFIA can be divided into seven (7) levels of responsibility with level 1 being the lowest responsibility and level 7 being the highest. Responsibilities of employees appointed at level 1 would be to follow, level 2 assist, level 3 apply, level 4 enable, level 5 ensure and advise, level 6 initiate and influence and level 7 to set strategy, inspire and mobilise. These levels of responsibility intersect with generic attributes that characterise the level of responsibility in terms of autonomy, influence, complexity, knowledge and business skills generally expected of employee roles. In other words, level 7's description of autonomy, influence, complexity, knowledge and business skills would be tantamount to the role of Chief Knowledge Officer (CKO), while a level 2 role would be

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assigned to a knowledge professional that maintains a KM database. In SFIA there is no level 1 role assigned for KM, which is indicative that the most basic level of responsibility is not present in KM. SFIA furthermore distinguishes between skills (behavioural and professional), and knowledge (technical, tools and methodologies, and context) depicting where experience intersects these. Qualifications and certifications are foundational to knowledge and skills and are graphically depicted in Figure 1.

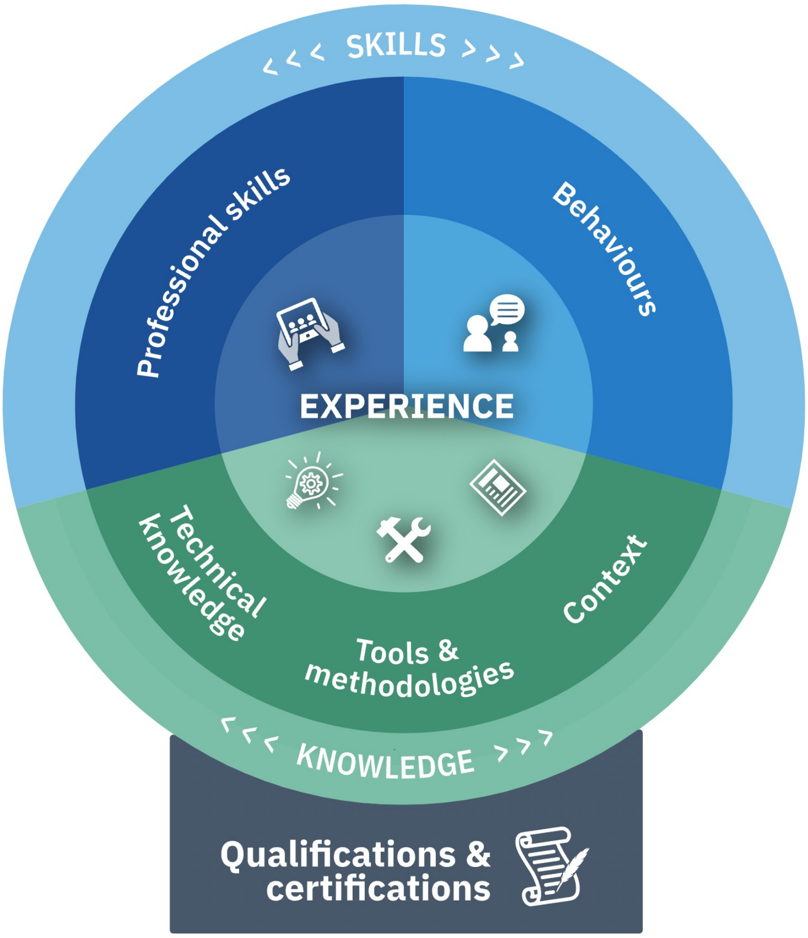

Figure 1: Graphical representation of knowledge, experience, skills, qualification, and certification (S.F.I.A., 2023)

While all the above frameworks and research on skills and capabilities for KM have been discussed (Ehlers & Kellermann, 2019; KMSA, 2022; Mabe & Bwalya, 2022; Rhem, 2017) the SFIA framework is selected for this research because it is a global common reference for skills and competency for the digital world. It is an evolving document developed by an evolving community of practice, extensively used and led by industry and business to describe the professional capability, skills proficiency and professional competency of digital world job roles and job architecture (S.F.I.A., 2023). As it is designed by practitioners for practitioners it already represents the codified voices of the practitioners in their expectation of what incumbents should be adhering to which therefore addresses the first research objective of this study.

3 METHODOLOGY

SFIA is foundational to the methods applied in this study in order to address the second objective of the study namely to assess the current curriculum offerings and explore curriculum linkages for the multidisciplinary discipline of knowledge management. The SFIA KM level descriptors are provided in Table 2.

Table 2: SFIA KM Level descriptors (S.F.I.A., 2023)

Levels	Description
SFIA Level 2: Assist	
	- Maintains a KM database. - Leverages knowledge of a specialism to capture and classify content, taking expert advice when required.
SFIA Level 3: Apply	
	- Maintains KM systems and content to meet business needs. - Supports others to enable them to complete KM activities and form KM habits. - Supports changes to work practices to support the capture and use of knowledge. - Reports on the progress of KM activities. - Configures and develops KM systems and standards.
SFIA Level 4: Enable	
	- Organises knowledge assets and oversees the life cycle of identifying, capturing, classifying, storing, and maintaining assets. - Facilitates sharing, collaboration and communication of knowledge. - Implements specific KM initiatives. - Monitors the use and impact of knowledge. - Interrogates existing knowledge content to identify issues, risks, and opportunities.
SFIA Level 5: Ensure, advise	
	- Develops and implements KM processes and behaviours. - Provides advice, guidance, and support to help people to adopt and embed KM. Contributes to the definition of policies, standards, and guidelines for KM. - Evaluates and selects KM methods and tools. Promotes collaborative technologies, processes and behaviours to facilitate sharing of ideas and work knowledge. - Shares ideas and examples of existing practices. Implements KM at programme, project and team levels.
SFIA Level 6: Initiate. influence	
	- Develops organisational policies, standards, and guidelines for KM. - Champions and leads in the development of an organisational KM approach. Shares different approaches for knowledge sharing across communities of practice, business units, and networks. - Promotes knowledge-sharing through operational business processes and systems. Monitors and evaluates knowledge-sharing initiatives. - Manages reviews of the benefits and value of KM. Identifies and recommends improvements.

[continued ...]

Table 2: [… continued]

Levels	Description
SFIA Level 7: Set strategy, inspire, mobilise	
	- Develops an organisation-wide KM strategy and leads the creation of a KM culture. - Embeds KM across business units and develops strategic KM capabilities. - Reinforces the importance of knowledge sharing by aligning individual and organisational objectives and rewards. - Identifies opportunities for strategic relationships or partnerships with customers, suppliers, and partners.

The KM level descriptors in SFIA clearly indicate the people, process, organisation and technology aspects typical in working with information and knowledge. The people-process-technology triad or the people-process-technology-content-governance quintet of knowledge-enabled organisations triggered the next multidisciplinary step of the methodology.

A desktop study using purposive sampling of study guides for the modules in the Department of Information Science at the University of Pretoria that includes KM theory and practice was thematically analysed. Six modules' study guides met the criteria. After data familiarisation, codes were generated and themes constructed and then revised. The KM content offered in each of the study guides was compared to the level descriptors of SFIA. The curricula for computer science and informatics was analysed to determine linkages or the potential for linkages for technology and tool development, system and process support for KM. These three desktop analyses form part of the past and present view into the curricula that can contribute to the skills development of KM graduates and addressed the second objective of the study.

The methodology applied in addressing the third objective of the research was to pilot a distributed digital ethnographic methodology that can be used to collect micro-narratives from employers as a partner, students as a partner, the KM practitioner as a partner and other academics involved in KM tuition. For this section of the research, Sensemaker® as a distributed digital ethnographic methodology was used to collect micro-narratives from a context and analysed to find emergent patterns from the perceptions and experiences of the contributor. Digital or virtual ethnographies are not really different from traditional ethnographies (Pickard, 2013). This paper reports on the results of 13 respondents who formed part of the pilot test of the collector instrument design using Sensemaker® as a distributed digital ethnographic methodology.

4 FINDINGS

The three desktop studies' findings are discussed followed by a brief discussion of the interim findings from the pilot study that shows why such a comparative study is necessary and will add value to the further development of the ethnographic collector.

4.1 Knowledge management curricula: Information Science

Information science is a discipline that explores the behaviour and properties of information (Borko, 1968). "It brings together and uses the theories, principles, techniques, and technologies of a variety of disciplines" to address information problems (Williams, 1988). These disciplines can include computer sciences, informatics, cognitive science, psychology, linguistics, sociology, management science, library science and KM (Kebede, 2010; Williams, 1988).

The demand for KM material is growing in South Africa, particularly in the discipline of information science. As a multidisciplinary field, KM blends a variety of concepts, theories, and methods from several disciplines. Although the notion of KM began in the business world, it has drawn professionals from other disciplines, notably Library and Information Science (LIS), who are interested in KM (Husain & Nazim, 2015; Roknuzzaman & Umemoto, 2010). Professionals with an Information Science degree have the knowledge and skills to successfully collect, organise, analyse, and disseminate information. In a knowledge-driven economy, firms understand the need for using their intellectual capital to obtain a competitive advantage. Businesses can use KM strategies to utilise internal information, improve decision-making processes, stimulate innovation, and improve overall organisational performance.

Within the University of Pretoria, the Department of Information Science offers numerous undergraduate as well as postgraduate modules in KM. These modules include:

- **INL 130** (Personal Information Management) on the first-year level: This module introduces students to information and KM on a personal level. It endeavours to build students' understanding of the key definitions, concepts and theories related to KM.

- **INL 310** (Information Organisation) on third-year level: This module builds on students' understanding of information management from the first-year level and takes on a more practical perspective which includes the introduction of KM enablers in organisations (e.g. organisational culture and learning organisations).

- **INL 320** (Information and Knowledge Management) on third-year level: This module focuses on information and KM at an operational level and introduces information and KM at a corporate strategic level, thus, taking on an organisational perspective of KM.

- **INY 713** (Information and Knowledge Management (I)) on Honours level: This module delves deeper into the use and application of theoretical frameworks of information and KM at a corporate strategic level. It also covers information and KM enablers in organisations (e.g. leadership, corporate culture, organisational learning, strategy, laws and policies, measurement and information technology).

- **INY 716** (Information and Knowledge Management (II)) on Honours level: This module offers students the opportunity to integrate and apply their learnt knowledge (undergraduate curricula), lived experiences (personal and business environment), competencies and skills of KM to develop, implement and evaluate KM strategies. It introduces students to advanced KM models and frameworks, a selection of KM theories, the role of KM in resiliency management, and trending issues in the field of KM.

- **MIT 890** (Data, Information and Knowledge Management) at Master's level: This module builds on students' understanding of Data Management (DM), Information Management (IM) and KM. It highlights the role of Information Technology (IT) in IM and KM, issues underlying the design and use of KM systems and advocates the benefits and value of designing a formal KM programme for organisations.

These modules follow a building block approach to encourage the development of students' understanding of KM from lower-level cognitive skills, starting on the first-year level, to higher-order cognitive skills on the Master's level. Therefore, each module forms the basis for the next offered in the information science curriculum. It promotes the movement of lower-order thinking to higher-order thinking. Thus, requiring students to move from memorising knowledge (e.g. what is KM) to applying, evaluating and creating new knowledge (e.g. KM strategy).

Applying the methodology mentioned in Section 3, Table 3 indicates the themes that were identified in correlation to the SFIA KM level descriptors.

Table 3: Undergraduate and postgraduate KM themes identified in the information science curriculum

Theme	Modules	SFIA KM level descriptors
Information Management (definitions, concepts and theories)	INL 130 (personal KM) INL 310 INL 320 (organisational KM) INY 713 MIT 890	Level 2 Level 3 Level 4 Level 3 Level 2
Knowledge Management (definitions, concepts and theories)	INL 130 INL 320 INY 713 INY 716 MIT 890	Level 2 Level 2 Level 3 Level 4 Level 3
Lifecycle of IM and KM	INL 130	Level 2
Information Overload Information Audits	INL 130 INL 130 INL 320 MIT 890	Level 2 Level 2 Level 4 Level 5
Knowledge Audits	INL 320 MIT 890	Level 2 Level 5
Sense- and Decision-Making	INL 320	Level 3
Knowledge Worker (Skills, responsibilities and Careers)	INL 130 INL 320	Level 2 Level 3
Organisation Culture and Learning	INL 310 INL 320 INY 713	Level 2 Level 3 Level 3

[continued …]

Table 3: [...continued]

Theme	**Modules**	**SFIA KM level descriptors**
KM Processes, Models, Tools and Metrics	INL 320	Level 3
		Level 4
	INY 713	Level 2
	INY 716	Level 3
KM Activities (Knowledge Creation, Capture, Coding and Sharing)	INL 320	Level 5
		Level 6
	MIT 890	Level 3
KM Strategy	INL 320	Level 2
	INY 713	Level 3
	MIT 890	Level 5
Knowledge Society	INL 320	Level 2
	INY 716	Level 3
		Level 4

In the following section, the KM links within the Department of Computer Science at the University of Pretoria are discussed.

4.2 Possible knowledge management links with Computer Science

The discipline of computer science considers the theoretical and practical foundations for the development of algorithms and software in order to store, manage and process information. The work a computer scientist engages in affects the daily life of every human being in the world today (ACM, 2023). A curriculum in computer science will therefore include modules in coding in support of structures and techniques to logically organise and manipulate the information, amongst other foundational modules (Marshall, 2017).

The modules presented in the computer science curriculum at the University of Pretoria that will enable the management of knowledge include modules that focus on (Marshall, 2011):

- Programming. COS 132 (Imperative programming) and COS 110 (Program Design: Introduction) provide the foundations in programming on which the modules at a higher year level rely.
- Organisation of data (or information) and the storage thereof in terms of data structures and algorithms; and structured, semi-structured and unstructured database systems. Data structures and algorithms (COS 212) make use of the programming building blocks to provide structures coded to manage the organisation of data/information in memory. The same algorithms and data structures are used to manage the efficient querying and retrieval of data/information from database systems (COS 221 (Database systems) and COS 326 (Advanced database systems)) for use in KM.
- Software development and the development of a relatively large project following a software engineering approach for a client. Software development and engineering rely on being able to model software systems. These software systems manage and present the

data and information in the data structures and database systems. These concepts are taught in COS 214 (Software modelling) and COS 301 (Software Engineering) respectively.

- Artificial intelligence. The principles required to develop and consequently design algorithms for a system that can assimilate data and information and populate knowledge systems are provided in COS 314. On the postgraduate level further artificial intelligence techniques, including clustering, heuristics, natural language processing and generative algorithms are presented.
- Programming. COS 132 (Imperative programming) and COS 110 (Program Design: Introduction) provide the foundations in programming on which the modules at a higher year level rely.
- Organisation of data (or information) and the storage thereof in terms of data structures and algorithms; and structured, semi-structured and unstructured database systems. Data structures and algorithms (COS 212) make use of the programming building blocks to provide structures coded to manage the organisation of data/information in memory. The same algorithms and data structures are used to manage the efficient querying and retrieval of data/information from database systems (COS 221 (Database systems) and COS 326 (Advanced database systems)) for use in KM.
- Software development and the development of a relatively large project following a software engineering approach for a client. Software development and engineering rely on being able to model software systems. These software systems manage and present the data and information in the data structures and database systems. These concepts are taught in COS 214 (Software modelling) and COS 301 (Software Engineering) respectively.
- Artificial intelligence. The principles required to develop and consequently design algorithms for a system that can assimilate data and information and populate knowledge systems are provided in COS 314. On the postgraduate level further artificial intelligence techniques, including clustering, heuristics, natural language processing and generative algorithms are presented.

Computer science does not directly present modules in KM. It does present modules that will enable the development of tools for specific KM requirements. The same analysis was done for Informatics.

4.3 Possible knowledge management links with Informatics

Informatics is concerned with the design and development of information systems that support organisational processes, to make them more efficient and effective. The field of informatics education is dynamic (Smuts & Hattingh, 2019) in support of the dynamic nature of the organisational environments in which informatics graduates will be employed. Informatics graduates are required to understand, interpret and analyse the context of organisational system problems, have the technical skills to design and develop information systems to address organisational system problems, and have soft skills to accomplish this.

The informatics curriculum, therefore, needs to be designed in such a way as to expose students to the complexities of an organisational environment and develop technical and soft skills. At the University of Pretoria, the informatics curriculum that will enable KM focuses on:

- Systems analysis and design (INF 171 and INF 271). The first-year curriculum introduces students to systems thinking, business processes, systems development methodologies, requirements-gathering techniques, project management and modelling languages. Students are introduced to the concept of data and the flow and modelling of data through a system. The knowledge is internalised through small, often independent case studies. In the second year, the curriculum expands on these concepts by exploring the concepts more in-depth, in addition to learning additional modelling techniques. Students are introduced to input (interface) and output design principles. Students internalise their knowledge by working in a team to plan and design a solution to a complex case study using project management and modelling tools.

- Programming (INF 154, INF 164, INF 272 and INF 354). Students are not required to have any programming knowledge before commencing their informatics studies. Consequently, the first-year programming modules introduce programming concepts and foundational knowledge needed for the forthcoming years of study. In the second year of study, students apply the model view controller (MVC) paradigm for web development, connect to a database, do object-oriented programming, and create a full client-server web-based application. During the final year of study, students are required to learn an additional programming language and advanced concepts that will enable them to choose a programming environment in which they can deliver their capstone project.

- Database design and development (INF 214 and INF 261). One of the key components of an Information System is a database. Students are introduced to the concept of data and the modelling of data in their first-year systems analysis and design modules. In the second year, students are required to extend their knowledge to the design and development of a relational database.

- Elective subjects. Students are required to combine their informatics modules with different streams of electives, depending on their interests. However, all of the informatics students are required to have an introduction to Business Management.

- Capstone module (INF 370). The learning across the above-mentioned learning areas is presented in a scaffolded approach (Matook et al., 2023) by exposing students to new terminology (data) and concepts in their first and second year of studies where they make sense of it through case study scenarios. However, in their third year of study, students are required to demonstrate their knowledge through project-based learning (Weilbach & Hattingh, 2022), employing a capstone project for a "real-life" client. During the capstone project, students demonstrate the knowledge they acquired throughout their preceding years of study by planning, designing and developing a turn-key solution for a client with an existing business problem. Whilst working on set deadlines, students demonstrate their technical skills and soft skills, a requirement for "industry-ready" graduates (Smuts & Hattingh, 2019).

Similar to computer science, informatics does not have specific KM modules on the undergraduate level, it rather presents modules that promote the transfer and conversion of knowledge. However, informatics offers a module dedicated to Data, Information and Knowledge Management (MIT 846) in the Master's (with coursework) programme. A requirement for this programme is that students need work experience within an Information Technology (IT) role for a required number of years. The reason for this requirement is that the programme, and the module specifically, require that students understand the importance of knowledge as an organisational asset. The module provides students with an overview of KM, and how IT can be used to enable KM. It further exposes students to the appropriate data analytics methods and modelling techniques.

Through the three desktop studies the existing curriculum offerings and the connections with KM were analysed. The second part of the methods applied in the research forms a part of ongoing research to collect ethnographic narratives from employers as a partner, students as a partner, the KM practitioner as a partner and other academics involved in KM tuition. Sensemaker® as a distributed digital ethnographic methodology was piloted and these results are reported here.

4.4 Interim curricula results from a global perspective

The first contributors to this portion of the research were participants that were part of a panel discussion on making sense of the KM curriculum. This group of 13 academic respondents (Table 4) formed part of the pilot test of the instrument designed as a collector. Their data is reported as an indication of why such a comparative study is necessary and will add value to the further development of the ethnographic collector.

As an ethnographic approach, Sensemaker® enables the capture of the multiplicity of voices in what they notice and observe in their encounters, speculative thinking and experiences of the KM curriculum and the changing demands for KM competencies in the workplace. This has the potential to complement and expand on the thematic analysis of the curriculum as approved by the university (and other relevant authorities) and informed by standards and frameworks. The Sensemaker® results can be used to clarify and contextualise the thematic analysis but also have the potential to identify potential discrepancies, gaps, redundancies and lack of coherence between the approved curriculum and the curriculum as experienced by academics, the student and the KM practitioner in the workplace. Sensemaker® gives access to

Table 4: Profile of responses

I am located in		
Sub-Saharan Africa	8	62%
North America (US & Canada)	3	23%
Europe and UK	1	8%
Prefer not to say	1	8%
In my institution, KM is situated in		
Information Science programmes	9	69%
IT programmes	3	23%
LIS programmes	2	15%
Business and management programmes	–	
Other	–	
My reflection is mostly on		
KM curricula in my institution	5	38%
KM curricula in general	4	31%
N/A	4	31%
Who should hear about my entry		
Institutions across the world	8	62%
N/A	3	23%
Only my department or institution	2	15%
Other institutions in my country	–	
Other institutions in my region	–	

everyday forms of social knowledge (thoughts and experiences) and helps reveal elements that inform the decisions and actions that shape our realities, collectively painting a bigger picture of perspective on a given issue (Snowden et al., 2021). It enriches and nuances captured thoughts and experiences (called micro-narratives or stories), as respondents are invited to self-analyse and interpret them via different forms of signifiers such as triads, dyads, and multiple-choice questions (see Figure 2 and the forthcoming discussion). The quantitative data collected through these signifiers provides a means to profile, analyse and compare the nature and prevalence of demands on the KM curriculum from the relevant voices in narrative or qualitative form.

With the small sample size of this pilot collection, comparative analysis based on demographic categories, such as region, is not included in the analysis. The profile of responses received is summarised in Figure 2.

The first emerging pattern from the preliminary results shows that the perception from academics is that the KM curriculum development should focus on functional knowledge and

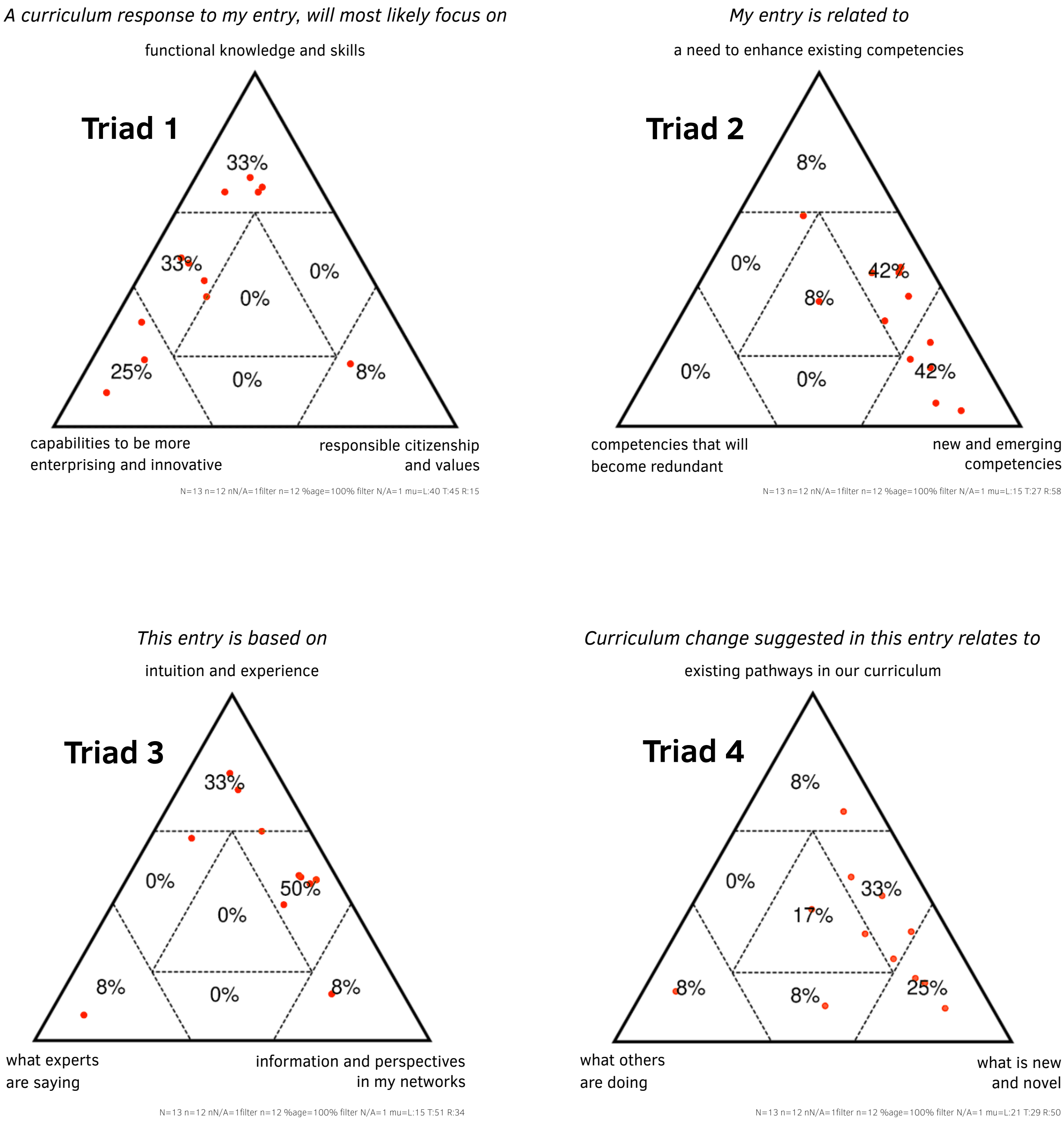

Figure 2: Overview of results from the triads

skills combined with the capabilities to be more enterprising and innovative (Figure 2, Triad 1). The low prevalence of *responsible citizenship and values* in Triad 1 requires further analysis in comparison with the perceptions from a broader pool of academics, students and practitioners, to ascertain if there is a potential negligence or understatement of this aspect in the outlook on the KM curriculum going forward in academic circles or if this aspect is already sufficiently covered. The outlook as represented in Triad 2 indicates that academics acknowledge that the curriculum should take cognisance of changes to existing competencies (42%), as well as new and emerging competencies (42%). The perspective in Triad 4 is that these are both building on existing competencies covered in the curriculum (33%) and inclusion of new content in the curriculum (25%). There is, in this initial pool of respondents, no explicit recognition of potential redundant competencies that should be removed from the curriculum in Triad 2.

The evaluation of the KM curriculum by academics as either faddish (42%) or stagnant (58%) in Dyad 1 (Figure 3), stems then from the need to update or expand on existing competencies to be relevant to the new and emerging competencies perceived to be required in the workplace, and not the exclusion of potentially redundant competencies that are included in the curriculum. This pattern also requires further inspection and comparison with more voices from all co-creators of the curriculum.

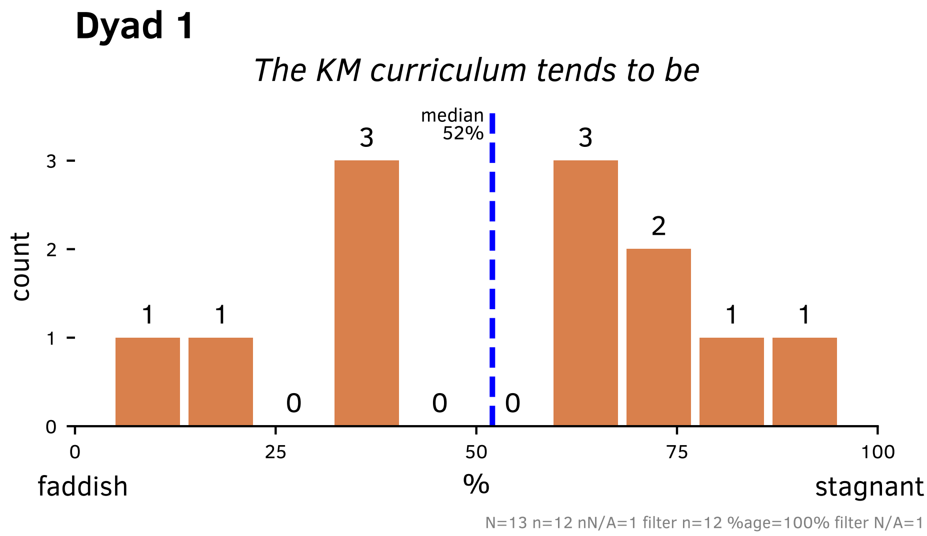

Figure 3: Overview of results from the dyad

A second emerging pattern shows a pattern of expansion and update of the existing curricula (labelled as existing pathways) in Triad 4, which is similar to the pattern in Triad 2. There is also a correlation in the perception that KM Curriculum development will be about what is new and novel (Triad 4), and new and emerging competencies (Triad 2). New and emerging competencies are of higher prevalence (42%) than the perception of what is new and novel for the KM curriculum (25%), which suggests that the perception is that the demand for

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capabilities from the workplace in the context of accelerated change will not be completely disruptive and will to a large extent be an adaptation of the existing curricula (33%)in Triad 4). A pattern that is relevant to the transdisciplinary nature of this study, is a low attribution of noticings and reflections that are informed by experts (Triad 3) or by others (Triad 3). This could be indicative of a siloed approach in curriculation, and a need for comparative analysis across curricula and actors as is proposed in this study. It will also enhance and supplement the formative role of autobiographical referencing in curriculum development and enactment which is a marked pattern in Triad 3 where 33%)indicated that their curriculum reflections are based on intuition and experience (label selected as a proxy for autobiographic memory or referencing) and a further 50%)that is based on a combination of intuition and experience with information in their networks that includes students, industry partners and practitioners. Autobiographic references are thus a strong filter for information from networks. The role of autobiographic referencing in curriculation is discussed by Short (1991). It is recommended that the signification framework is reviewed to include a signifier to gauge the potential implications of siloed tendencies as experienced by students and practitioners, like duplication, potential confusion and difficulty for students to understand and bring together the synergies in the curricula of different subjects in a programme and demands of the workplace.

The third pattern is based on a thematic analysis of the narrative fragments offered by the respondents. The diversity of the fragments received, even from such a small sample in the pilot, is a positive indicator of the value of the Sensemaker® method as part of a curriculum study. Three themes were identified:

- The demand to be enterprising and innovative is supported by the necessary functional skills (Triad 1), to be able to keep up with the development of new technologies, methods and societal needs such as more accessible knowledge for those with disabilities.
- The second theme is related to the first theme and speaks to the relevance and demand for soft skills to be able to keep up and respond to the changing demands.
- The last theme puts the identity and understanding of KM as a distinct discipline and practice on the agenda, and how KM relates and interacts with other disciplines and practices. This theme also supports the need for a transdisciplinary curriculum study that is informed by a multiplicity of voices.

These interim results from the pilot study allow for the further development of the collector and will be reported on once a larger sample has been collected.

4.5 Summary of the findings

The desktop analysis first revealed that the information science curriculum offering for KM focuses teaching concepts on the SFIA level descriptors 2 and 3 mostly with limited teaching happening for levels 4, 5 and 6. While this is to be expected considering that higher levels of

SFIA level descriptors require job experience, there are most likely opportunities to develop curriculum offerings in these levels, especially postgraduate curriculum levels.

With information science mostly focussed on the people side of the people-process-technology triad the desktop study further emphasised the potential for process and technology linkages that could collaborate with computer science and informatics.

The pilot study confirmed Sensemaker® as a potentially valuable ethnographic methodology and while the 13 academic responses already revealed interesting patterns as indicated in Section 4.4 the pilot now needs to be rolled out to collect micro-narratives from all relevant curriculum co-creators that have been identified.

5 CONCLUSION

This project afforded the authors the opportunity to critically reflect on the current reality of curriculum design for KM practitioners. By assessing the future skills discourse and comparing current curricula to what is potentially expected to be needed in future, dedicated academics critically question the relevance of content and tuition for graduates. The research also afforded the opportunity to analyse the Sensemaker® collector in its piloting stage to test the applicability of the instrument for further collection from co-creating curriculum partners as the multitude of voices that should be acknowledged and listened to in the process of curriculum design.

As uncertain as the future always has been, the reality remains that institutions of higher learning are required to push the boundaries by offering qualifications that are relevant to whatever the future may hold. Graduates need to be skilled to face the future. Although foundational and technical knowledge, or discipline tools and methodologies are needed, it has become clear that it is through behaviours and soft skills that graduates will find the real resilience to face whatever the future may hold.

This study is at its inception and the collective voices of all co-create curriculum partners are needed to form a holistic view of what is required to mould the KM professional that would serve knowledge workers in Society 5.0. Without endangering the freedom of academics and researchers to develop curricula at the frontiers of a discipline, the student, industry and KM practitioner as a partner are now needed more than ever before to co-create the curriculum for the KM practitioner of the future.

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Letter to the Editor: Advancements in Digital Health Technologies

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Dear editor and readers of the South African Computer Journal,

We are pleased to provide an update from the research team at the Microprocessor Technology Lab, Glushkov Institute of Cybernetics, National Academy of Sciences of Ukraine. Our recent research endeavours are focused on enhancing the monitoring and rehabilitation of military personnel, particularly in response to the challenges posed by combat conditions, and post-traumatic stress disorder (PTSD). We invite researchers, and industry partners to collaborate on these groundbreaking initiatives, and encourage viewing our summary video featuring Illya Chaikovsky (Chaikovsky, 2024) for a comprehensive overview of our research. Led by scientific supervisors Oleksandr Palagin (Academician of the National Academy of Sciences of Ukraine, Doctor of Sciences in Technical Sciences, PhD, Professor, Honored Inventor of Ukraine, Deputy Director for Research of Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine, Head of the Microprocessor Technology Lab), and Illya Chaikovsky (M.D., PhD multiple, FRMS, PMESC, Lead Researcher of Department of Sensory Devices, Systems and Technologies of Noncontact Diagnostics, Glushkov Institute of Cybernetics), our research team has made significant strides in understanding the psychophysiological state of servicemen, and developing innovative hybrid cloud solutions to support their well-being and operational readiness.

Our research has underscored the critical importance of monitoring the psychophysiological state of servicemen (Bocharov et al., 2023), especially in combat environments where success in tasks is significantly influenced by their mental and emotional condition. Drawing on insights from the combat experience of the Armed Forces of Ukraine, particularly in the face of large-scale aggression by Russia, we have highlighted the necessity of real-time monitoring, and processing to optimise training regimes, and ensure the readiness of servicemen for combat tasks.

The onset of war aggression and invasion has posed unprecedented challenges to the medical rehabilitation system in Ukraine, particularly in addressing the needs of individuals suffering from PTSD, and combat-related mental trauma. Recognising the urgency of this issue, both societal stakeholders, and the Ministry of Health of Ukraine have prioritised the development

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of rehabilitation strategies. Our research emphasises the integration of hybrid e-rehabilitation technologies, coupled with objective monitoring methods, to extend the reach of rehabilitation services, and provide personalised care to affected individuals.

In response to the limitations of traditional rehabilitation centers, we have developed a hybrid cloud-based platform – the patient-centered Smart system of telemedicine support for hybrid e-rehabilitation activities (Malakhov, 2022, 2023a, 2023b; Palagin, Malakhov, Velychko & Semykopna, 2022). This innovative approach features cutting-edge technologies such as remote patient monitoring via telemetry Internet of Medical Things (IoMT) devices, and cognitive support systems to deliver tailored rehabilitation interventions remotely. By combining these technologies with intelligent information systems, we aim to enhance the effectiveness and accessibility of rehabilitation services for military personnel, and other individuals in need.

Our research has culminated in the validation of portable hardware and software complexes for monitoring the psychophysiological state of military personnel. These validated methods offer commanders valuable insights into individual readiness levels, aiding in decision-making related to combat task execution. Moving forward, we remain committed to further refining these technologies, and expanding their application in supporting the well-being and performance of military personnel.

In addition to our ongoing efforts in monitoring and rehabilitating military personnel, we are excited to share insights from our latest research endeavors in the burgeoning field of digital health and the IoMT. Our team is currently focused on the development of groundbreaking information technology for computerised electrocardiography, representing a significant step forward in healthcare innovation. The primary objective of our research is to enhance the diagnostic capabilities of electrocardiography using IoMT devices to capture subtle changes (Chaikovsky et al., 2022) in cardiac signals that may go unnoticed during routine analysis. To address this challenge, we have pioneered an original method and software for scaling electrocardiograms (ECGs), and heart rate variability (HRV), enabling healthcare professionals to extract deeper insights from these vital physiological indicators (Chaikovsky et al., 2023).

By harnessing the power of IoMT devices, and advanced signal processing techniques, our innovative approach aims to transform the way cardiac data is analyzed and interpreted. Through precise scaling and analysis of ECG signals, we seek to uncover valuable diagnostic information that can inform personalised treatment strategies and improve patient outcomes. By bridging the gap between traditional diagnostic methods and cutting-edge digital solutions, we are paving the way for a new era of precision medicine that prioritises individualised care and proactive health management.

To provide a comprehensive overview of our research, we have recorded a short video featuring Illya Chaikovsky (Chaikovsky, 2024). In this video, Illya Chaikovsky succinctly summarises our findings and discusses the implications of our work in the field of digital health and IoMT. We encourage you to watch this video for a more in-depth understanding of our research, and its potential impact.

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We gratefully acknowledge the support received from various funding sources, including grants from the National Research Foundation of Ukraine. These resources have enabled us to pursue transdisciplinary research initiatives aimed at addressing pressing societal needs. The results of these studies were obtained during 2017–2024:

- According to the scientific directions defined by the Strategic Defense Bulletin of Ukraine, put into effect by the Decree of the President of Ukraine of June 6, 2016 No. 240/2016. In particular, the research was carried out in the areas defined by Strategic Goal 5 "Professionalisation of the Defense Forces and the Creation of the Necessary Military Reserve" in part of Operational Goal 5.2 "Improving the system of military education and personnel training".
- Grant contract of the National Research Foundation of Ukraine – "Trans-disciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP)" (Palagin, Malakhov, Velychko, Semykopna & Shchurov, 2022; Palagin & Petrenko, 2018), application ID: 2020.01/0245 (2020–2021, project was successfully completed).
- Grant contract of the National Research Foundation of Ukraine – "Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modeling" (Malakhov, 2023b; Malakhov, 2024), application ID: 2021.01/0136 (2022–2024, project is still in progress).

Sincerely,

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