SACLA conference 2026



Proceedings of the 55th Annual Conference of the Southern African Computer Lecturers' Association

Fundamentals First: Learning to Walk Before Running in the Age of Emerging Technologies

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July 15 - 17, 2026

Cape Town, South Africa

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Preface

The 55th Annual Conference of the Southern African Computer Lecturers' Association (SACLA) was held from 15 to 17 July 2026 in Cape Town, South Africa, hosted by the School of IT of the University of Cape Town. As an in-person event, SACLA2026 continued its tradition of fostering academic exchange and professional collaboration in the fields of Computer Science, Information Systems, and Information Technology education.

With the theme "*Fundamentals First: Learning to Walk Before Running in the Age of Emerging Technologies,*" this year's conference acknowledges the impact of emerging technologies on our fields and how we approach computing education. While these tools allow students to rapidly build technical solutions to complex problems, a careful balance is required. We, as computing academics, have the responsibility to ensure that, even if students can now "*run*" by leveraging advanced tech, we continue to instil the core fundamentals that underlie our computing disciplines. Ultimately, these foundational principles play an increasingly critical role in software architecture and systems engineering that form the cornerstone of successful projects. Critical inquiry and foundationally sound computational thinking, paired with robust ethical frameworks are key in understanding the true capabilities and limitations of emerging technologies and their responsible use in academia and beyond.

This volume comprises some 19 papers, representing ~36% of the 53 overall submissions received for SACLA 2026. These papers were accepted for publication after a rigorous double-blind peer-review process. Each submission was reviewed by at least two members of the international programme committee. Authors were required to respond to reviewer feedback with detailed rebuttals and change logs prior to publication, contributing to the high quality of the final papers included in these conference proceedings. More than 60% of the contributions in the proceedings emanate from multiple institutions. In addition to this volume, the 15 highest scoring papers after the peer review process were selected for inclusion in a Springer Communications in Computer and Information Science (CCIS) volume. In total, 34 papers were presented at the conference as indicated in the detailed programme. The SACLA Programme Committee extends sincere thanks to all authors, reviewers, session chairs, and delegates for their contributions.

The annual Head of Department (HOD) Colloquium was held to provide those academics in leadership positions with a forum to discuss topical issues in Southern African academic computing departments and the broader higher education landscape.

We trust that the discussions and ideas exchanged at SACLA 2026 will continue to inspire meaningful innovation and collaboration in the Southern African computing education community. We look forward to building on this momentum when the 56th Annual SACLA Conference will be hosted by the University of the Witwatersrand, Johannesburg, South Africa in 2027.

Dirk Snyman[1], Tendani Chimboza[1] and Janet Liebenberg[2]
SACLA 2026 Programme Chairs

[1] Centre for IT and National Development in Africa (CITANDA),
School of IT: Department of Information Systems,
University of Cape Town, South Africa
[2] School of Computer Science and Information Systems,
North-West University (Potchefstroom Campus), South Africa



Dear Author 17 July 2026

SACLA 2026 Conference Proceedings – DHET

The School of IT: Department of Information Systems at the University of Cape Town (UCT) hosted the SACLA 2026 conference in Cape Town from 15 to 17 July 2026 at the UCT Graduate School of Business Academic Conference Centre at the UCT Breakwater Campus. This letter serves to confirm that the Proceedings of the 55th Annual Conference of the Southern African Computer Lecturers' Association (SACLA 2025), ISBN 978-1-0483-3215-5 (e-book), has been published according to the full DHET criteria.

The SACLA 2026 international programme committee comprised 35 members. A rigorous double-blind peer review process was followed for all 53 submissions. Each submission was reviewed by at least two members of the program committee. The SACLA 2025 Conference Proceedings contains a collection of 19 accepted papers (representing 36% of the original submissions) presented at the SACLA 2026 conference.

The full papers published in the SACLA 2026 Conference Proceedings were contributed by authors from different institutions within South Africa and internationally. More than 60% of the contributions in the proceedings emanate from multiple institutions. The above information can be found on page i of the front matter of the SACLA 2026 Conference Proceedings, which is accessible at https://sacla2026.co.za/proceedings. Please contact the undersigned should more information be required.

Yours sincerely



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Venue

UCT Graduate School of Business (GSB) Conference Centre,
Protea Hotel Cape Town Waterfront Breakwater Lodge.

Sponsors

We would like to thank our generous sponsors for their contribution to SACLA 2026

Oracle Academy, University of Cape Town and Centre for IT and National Development in Africa, and the Institute of Information Technology Professionals (IITPSA)

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Academy

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Centre for IT and National Development **in Africa**

Advancing ICT for National Development in Africa



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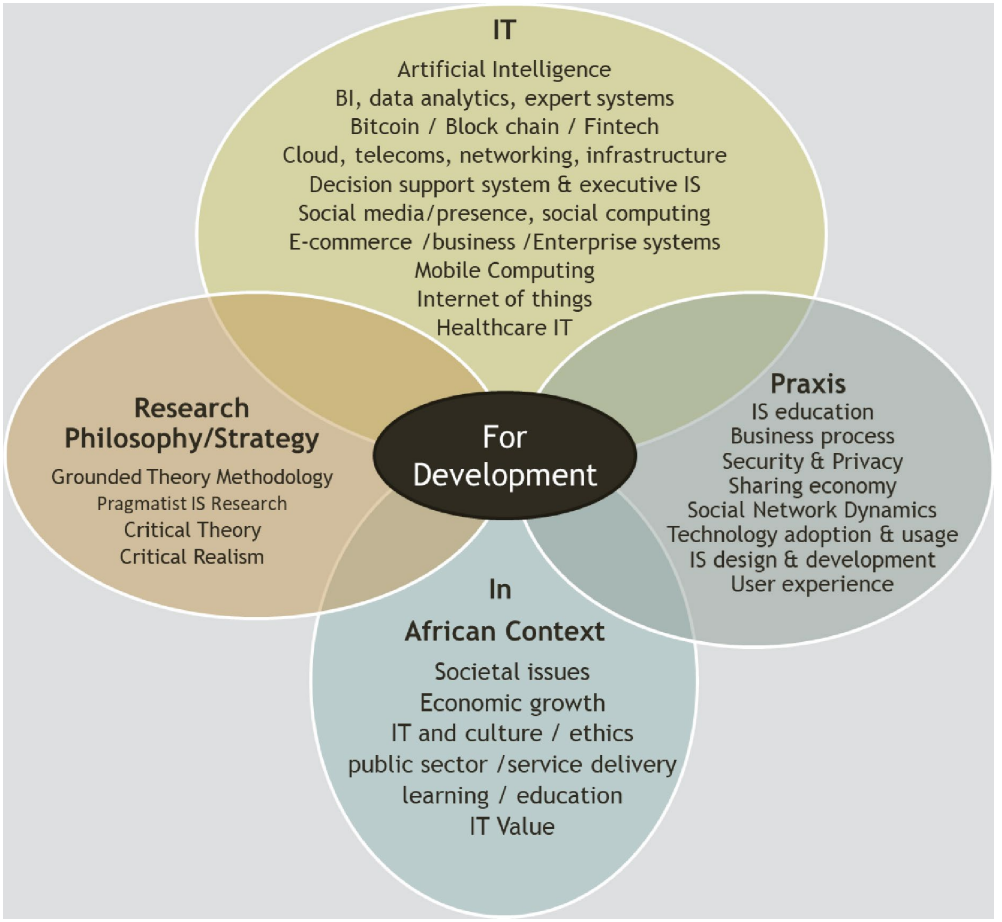
ESEFA DATA STORYTELLING AND VISUALIZATION COMPETITION (2024)

Research Mandate

CITANDA is a research unit housed within the Department of Information Systems at the University of Cape Town. It is the vehicle through which research by the department and interdisciplinary collaborators is branded and funded. It is a conduit for drawing together researchers.

Goals

- CITANDA aims to bring together researchers, projects, funders, and programmes focused on Information and Communication Technology (ICT) in the service of national development. Our approach to research is grounded in the discipline of IS, which is inter-disciplinary and allows systemic investigation of phenomena which emerge from complex interactions that take place between ICT, organisations, society and individuals, rather than any one of these elements in isolation.
- CITANDA is singularly focused on Africa. We strive to be the leading African centre for Information Systems research in Africa, producing world-class African scholars and internationally recognised research outputs and postgraduates. Our strategic location and role in Africa is acknowledged, and as such we place great emphasis on being both internationally recognised, as well as African in terms of research thrust and profile. CITANDA actively partners in interdisciplinary research that complements our educational and research programs. In particular, we engage in diverse-research aligned to our research themes.
- The membership of CITANDA includes all academic staff from the Department of Information Systems as well as our graduate students and research affiliates.



Research projects

- **C3SA:** https://c3sa.uct.ac.za/
- **ESEFA:** https://esefa.uct.ac.za/
- **Icomms:** https://sit.uct.ac.za/icomms
- **Fairwork:** https://www.news.uct.ac.za/article/-2019-03-29-rating-system-improves-working-conditions-on-digital-platforms

Research Associates:
https://sit.uct.ac.za/citanda/research-associates

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Message from the Conference Chairs

We are proud to welcome all delegates to the Mother City at the prestigious UCT Graduate School of Business Academic Conference Centre at the University of Cape Town's Breakwater Campus, situated at the historic Victoria and Alfred Waterfront. We trust that this 55th instalment of the annual SACLA conference will serve as a coming-together of likeminded academics and industry professionals to discuss the most pressing issues of the day in computing education and establish beneficial professional networks.

The conference theme, "Fundamentals First: Learning to Walk Before Running in the Age of Emerging Technologies," strongly resonates with our classroom experiences. Over the past 15 years, we have taught diverse cohorts across a wide spectrum of classes, ranging from introductory courses to final-year capstone projects. We are firm believers in the value of core principles within an increasingly distracted environment brought on by the current wave of disruptive technologies. While the advent of generative AI is certainly one of the most disruptive forces to date, history has taught us that throughout every major shift in computing disciplines, the core fundamentals remain indispensable to the toolkit of the contemporary computer scientist or information technologist. It is, therefore, our collective responsibility to continue to contribute to the high quality of computing education that has been established at the southern tip of Africa, ensuring we graduate students who are thoroughly equipped to navigate an ever-changing technological landscape.

We want to take this opportunity to thank our sponsors for their dedication to supporting Southern African computing education in general, and specifically their contributions that allow us to host this conference. As our Platinum Sponsor, we acknowledge with thanks the support provided by Oracle Academy, and as our Silver Sponsors, the contributions from the University of Cape Town Centre for IT and National Development in Africa (CITANDA), and the Institute of Information Technology Professionals (IITPSA) are similarly recognised.

From a practical perspective, we want to thank Renée Le Roux (Mongoose C&D) and the School of IT: Department of Information Systems, University of Cape Town, for supporting us in the organisational aspects. And, finally, we want to acknowledge the diligence of every member of the programme committee and all the authors whose hard work forms the basis of the conference and this publication as a record of the conference proceedings.

Dirk Snyman and Tendani Chimboza
SACLA 2026 Conference Chairs

Centre for IT and National Development in Africa (CITANDA)
School of IT: Department of Information Systems
University of Cape Town, South Africa

Organisation

The 55th Annual Conference of the Southern African Computer Lecturers' Association (SACLA 2026) was organised by the School of IT: Department of Information Systems, University of Cape Town, South Africa

SACLA President

Estelle Taylor, North-West University (Potchefstroom Campus), South Africa

Local Conference Committee

Conference chairs: Dirk Snyman and Tendani Chimboza University of Cape Town, ZA

Programme Committee Chairs (Technical Committee)

Dirk Snyman	University of Cape Town, ZA
Tendani Chimboza	University of Cape Town, ZA
Janet Liebenberg	North-West University, ZA

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Lynette Barnard	Nelson Mandela University, ZA	Wynand Nel	Akademia, ZA
Lynette Drevin	North-West University, ZA		

Conference Programme



Wednesday, 15 July 2026		
13:00 - 17:00	Registration	Foyer
14:00 - 17:00	SACLA HoD's Colloquium	Executive Room, Blok B
17:00 - 17:30	**Tea / Coffee**	**Executive Room, Blok B**
17:00 - 18:00	SACLA Executive Committee Meeting	Executive Room, Blok B
19:00 for 19:30	SACLA 2026 Welcome Cocktail	Two Oceans Aquarium

Thursday, 16 July 2026		
07:30 - 08:00	Registration	Foyer
08:00 - 08:30	Official Conference Opening & Welcome	Venue 1-2 Combined
08:30 - 09:00	Oracle Sponsor Presentation	Venue 1-2 Combined
09:00 - 10:00	Keynote Address: What are we really preparing students for? — Speaker: JT Janse van Rensburg	Venue 1-2 Combined
10:00 - 10:20	**Short break (Venue setup for parallel tracks)**	**Foyer / Venues**
Time	**Track A (Venue 1)**	**Track B (Venue 2)**
	Session 1A: Information Systems Education *Session Chair: Janet Liebenberg*	***Session 1B: Emerging Technologies & VR*** *Session chair: Japie Greeff*
10:20 - 10:40	"IT Governance Education: Reflections from a South African Postgraduate Programme" — Authors: Lynn Futcher, Mariana Gerber, Hettie Booysen and Johann Botha	"First-Year Computer Science and Informatics Students' Experiences of an Immersive Virtual Reality Application for Computer Hardware Assembly" — Authors: Nadean Barkhuizen, Benjamin Botha and Lizette de Wet
10:40 - 11:00	"Evaluating the Undergraduate Information Systems Curricula in South African Universities" — Authors: Kenneth Mashingaidze and Thembekile Mayayise	"Virtual Reality as a Method for Training Undergraduate Computer Science Students in CAT6 Network cable Termination: A Pilot study" — Authors: Maruping Kometsi and Benjamin Botha
11:00 - 11:20	"Towards Developing Business Process Analyst Competencies through Higher Education Curriculum" — Authors: Elizabeth Wamicha and Lisa Seymour	"A Concept Difficulty Analysis of Learning in a Flipped Distributed Systems Course" — Authors: Ijeoma Ezeji, Pragasen Mudali and Matthew Adigun
11:20 - 11:50	**Mid-Morning Tea & Coffee Break**	**Foyer**

Thursday, 16 July 2026 (Continued)		
	Session 3A: Curriculum Alignment Frameworks *Session chair: Carolien van den Berg*	***Session 2B: Cybersecurity & Academic Integrity*** *Session chair: Dirk Snyman*
11:50 - 12:10	"Perceptions of CS2023 and Accreditation in Africa: Opportunities and Challenges for Building Globally Competitive Computing Programmes" — Authors: Janet Liebenberg and Karen Bradshaw	"Navigating the Dual-Use Dilemma: Educational Benefits vs. Criminal Misuse of Accessible Attack Platforms" — Authors: Tapiwa Gundu
12:10 - 12:30	"The Cross-Module Integration Model (CMIM): Integrating Cross-Module Competencies in Undergraduate Computing Education" — Authors: Luke Coetzee, Michael de Jager and Lance Bunt	"Over-reliance on Artificial Intelligence by programming students at a South African university" — Authors: Kabelo Mosala and Walter Uys
12:30 - 12:50	"Aligning South African Undergraduate Computer Science Curricula to Job Requirements and Standard Knowledge Framework using Machine Learning" — Authors: Oluwafemi Oriola and Eduan Kotzé	[No talk scheduled]
12:50 - 13:50	**Lunch Break (1 Hour)**	**Restaurant / Foyer**
	Session 2A: Learning Analytics & Automated Assessment *Session chair: Andre Calitz*	***Session 3B: Software Engineering Education*** *Session chair: Aslam Safla*
13:50 - 14:10	"Semi-Automated Rubric-based Assessment for Computer Graphics Assignments" — Authors: Tristan Potgieter, Linda Marshall and Cobus Redelinghuys	"Attributes Influencing the Adoption of Test-Driven Development: An Empirical Investigation Among Novice Programmers" — Authors: Pieter Kruger and Guillaume Nel
14:10 - 14:30	"Automated Detection of Design Patterns using Vector-Based Graph Matching for Assessment" — Authors: Layla Olivier, Linda Marshall and Francois Redelinghuys	"A Comparative Case Study of Undergraduate Software Engineering Modules in Germany and South Africa" — Authors: Christian Kücherer, Brenda Scholtz and Janine Nel
14:30 - 14:50	"Automatic Detection of Pedagogical Misalignment Using Pretrained Language Models" — Authors: Deborah Olaniyan and Ruth Wario	"Designing Immersive Virtual Reality Learning Environments for Software Engineering: A Reflective Study" — Authors: Thirumala Naidoo and Sunet Eybers
14:50 - 15:10	**Afternoon Tea & Coffee Break**	**Foyer**

	Session 4A: Student Engagement & Retention *Session chair: Michael de Jager*	***Session 4B: AI & Language Models in Higher Ed*** *Session chair: Walter Uys*
15:10 - 15:30	"Beyond Satisfaction: Belonging Uncertainty, and Structural Attrition Risk in South African Computer Science Education" — Authors: Rouxan Fouché and Eduan Kotzé	"Generative AI: Insights from South African Higher Education Institutions" — Authors: Estelle Taylor, Andre Calitz and Margaret Cullen
15:30 - 15:50	"From Participation to Performance: The Impact of Gamified Engagement on First-Year Programming Academic Outcomes" — Authors: Marisa Venter	"Rethinking Presence in ODeL: Extending the Community of Inquiry Framework with Quasi-Presence in the Context of Generative AI" — Authors: Ronell van der Merwe
15:50 - 16:10	"Beyond Syntax: Metacognitive Enactment and Bottlenecks in CS1 Problem-Solving" — Authors: Karabo Matabane and Liezel Nel	"IS Education in the Age of GenAI: The Case for IBL and Adapted Assessment Models" — Authors: Malcolm Garbutt and Carolien van den Berg
16:10 - 17:00	**Dinner Preparation Buffer & Relaxation Window (50 Mins)**	**Breakwater Lodge Hotel**
17:00	Bus Departs for Conference Dinner	Main Entrance
18:00 - 21:30	SACLA 2026 Conference Dinner	The Tangram Restaurant (Durbanville Hills Winery)
22:00	Bus Returns	Breakwater Lodge Hotel

Friday, 17 July 2026

07:30 - 08:30	Registration	Foyer
08:30 - 08:40	Plenary: Sponsor Introductions	Venue 1-2 Combined
08:40 - 08:55	Sponsor Presentation: IITPSA (15 Min)	Venue 1-2 Combined
08:55 - 09:10	Sponsor Presentation: CITANDA (15 Min)	Venue 1-2 Combined
09:10 - 09:30	**Short break (Venue setup for parallel tracks)**	**Foyer / Venues**
Time	**Track A (Venue 1)**	**Track B (Venue 2)**
	Session 5A: Inclusion & Sustainability *Session chair: Bennie Botha*	***Session 5B: Graduate Competencies & Industry Links*** *Session chair: Annette van der Merwe*
09:30 - 09:50	"Integrating Artificial Intelligence Technologies into Higher Education to bridge the Digital Divide Gap for Learners" — Authors: Michele Devoti, Guidance Mthwazi and Adheesh Budree	"Industry Perspectives on Industry Advisory Board Effectiveness in IT Higher Education" — Authors: Estelle Taylor, Andre Calitz and Margaret Cullen
09:50 - 10:10	"Walking Before Running: A Staged Scaffolding Model for Fundamental Programming Skills" — Authors: Mokotsolane Mase and Liezel Nel	"Fundamentals First: A Reflective Design Science Framework for IT Graduate Programme Development" — Authors: Jt Janse van Rensburg
10:10 - 10:30	"Looking back before we look to the future: reflecting on a sustainable-smart transdisciplinary student project" — Authors: Carolien van den Berg and Belinda Verster	"The Problem of Bachelor's Dissertations in Computer Science, Informatics, and similar Academic Disciplines: an Experience-based Discussion" — Authors: Stefan Gruner and Linda Marshall
10:30 - 11:00	**Mid-Morning Tea & Coffee Break**	**Foyer**
	Session 6A: AI Pedagogies & Methodologies *Session chair: Estelle Taylor*	***Session 6B: Postgraduate Supervision & Design models*** *Session chair: JT Janse van Rensburg*
11:00 - 11:20	"Integration of Generative AI tools into the Programming Pedagogy: A conceptual framework" — Authors: Meke Kapepo, Salma Elfekri, Selwa Elfirdoussi and Hind Kabaili	"Redesigning an Honours Research Methodology Mod-ule Using a Hybrid Agile Approach to Enhance Student Self-Efficacy: An Analytical Autoethnography" — Authors: Marie Hattingh
11:20 - 11:40	"Understanding the Effect of Foundations Before Automation in AI-Assisted Programming Education: A Proposed Statistical Approach" — Authors: Michael Ajayi, Khulekani Mavundla and Jan Mentz	"The Value of Including a Research Alignment Plan in Honours Project Supervision" — Authors: Andre Calitz and Margaret Cullen
11:40 - 12:00	"Prompt Development: A Critical Realist's Approach to AI-supported Thematic Analysis" — Authors: Mark Brand, Jean Greyling and André Calitz	"Integrate Practice with Theory: A Design Model for Introducing Applied Security Thinking in Information Security" — Authors: Michael de Jager and Imelda Smit
12:00 - 13:00	SACLA 2026 AGM, Closing Remarks & Acknowledgments	Venue 1-2 Combined
13:00 - 14:00	**Lunch & Departure**	**Restaurant / Foyer**

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CITANDA

Centre for **IT** and National Development **in Africa**

Keynote address | Thursday, 16 July | 09:00 - 10:00

Keynote Address: What are we really preparing students for?
— Speaker: JT Janse van Rensburg

This keynote is sponsored by the UCT Centre for IT and National Development in Africa (CITANDA)

CITANDA | Centre for **IT** and National Development **in Africa**

Venues 1-2 Combined



Computer Science has never evolved as rapidly as it is today. New technologies emerge almost daily, AI is reshaping how software is developed, and universities face increasing pressure to produce graduates who are "future ready." But amidst all this change, one question has become increasingly difficult to answer: *What are we really preparing students for?*

After spending more than a decade teaching Computer Science, researching the gap between university and industry, and then crossing into industry to design graduate programmes and AI capability initiatives, Prof. JT Janse van Rensburg has had the unusual opportunity to observe the same challenge from both sides of the classroom.

This keynote is a reflection on that journey. Rather than focusing on the latest technologies, it invites the audience to step back and reconsider the enduring purpose of Computer Science education. In a profession where the tools change constantly, what should never change? Perhaps the most important lessons for preparing graduates for the future are not the newest ones at all.

Prof JT Janse van Rensburg is an AI Strategist at iqbusiness and an Extraordinary Professor at the Optentia Research Unit at North-West University. Her career has been defined by a single question: how do we prepare Computer Science graduates for successful professional practice?
JT spent more than a decade in academia teaching Computer Science, supervising postgraduate research, and completing a PhD that developed practical guidelines for bridging the gap between IT theory and industry practice. Her research focused on graduate capability, project-based learning, reflective practice, and strengthening collaboration between universities and industry.

Seeking to test those ideas beyond the classroom, JT transitioned into industry, where she worked in consulting, agile delivery, programme management, and graduate development before moving into AI strategy and organisational capability enablement. She has since designed and led graduate programmes, advised organisations on AI adoption, and helped teams navigate the changing relationship between technology, learning, and work.
Having worked on both sides of the university-industry divide, JT brings a rare perspective to the future of Computer Science education. Her keynote draws on more than fifteen years of research and practice to explore what has changed, what has remained constant, and what that means for preparing the next generation of computing professionals.

Papers selected for the Springer Communications in Computer and Information Science (CCIS) volume

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The following list comprises the top-ranked papers identified during the rigorous peer-review process. These papers were presented at the conference but are not included in this volume. They were selected for post-conference publication in:



***ICT Education: 55th Annual Conference of the Southern African Computer Lecturers' Association, SACLA 2026, Western Cape, South Africa, July 15–17, 2026, Revised Selected Papers*, Communications in Computer and Information Science (CCIS)**

Springer Nature.

Submission 15: IT Governance Education: Reflections from a South African Postgraduate Programme
Lynn Futcher, Mariana Gerber, Hettie Booysen, Johann Botha

Submission 16: Semi-Automated Rubric-based Assessment for Computer Graphics Assignments
Tristan Potgieter, Linda Marshall, Cobus Redelinghuys

Submission 17: Beyond Satisfaction: Belonging Uncertainty, and Structural Attrition Risk in South African Computer Science Education
Rouxan Fouché, Eduan Kotzé

Submission 22: Walking Before Running: A Staged Scaffolding Model for Fundamental Programming Skills
Mokotsolane Mase, Liezel Nel

Submission 26: Attributes Influencing the Adoption of Test-Driven Development: An Empirical Investigation Among Novice Programmers
Pieter Kruger, Guillaume Nel

Submission 28: IS Education in the Age of GenAI: The Case for IBL and Adapted Assessment Models
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Integrating Artificial Intelligence Technologies into Higher Education to bridge the Digital Divide Gap for Learners

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Abstract. This study examines the integration of artificial intelligence (AI) technologies in higher education and the influence they have in bridging the digital divide gap that exists amongst learners from differing socioeconomic backgrounds. The digital divide has resulted in negatively affecting the access to and use of digital resources for disadvantaged learners. Using an interpretivist, ethnographic approach, the study collected qualitative data from fifteen higher education learners from universities in the Western Cape. Thematic analysis as outlined by Braun and Clarke was used to analyse responses of an open-ended questionnaire. Focus was placed on AI's impact on digital literacy, learners' familiarity with AI-enabled tools, academic tasks affected by AI integration, and the relationship between higher education institutions and the integration of AI technology into academics. Key findings reveal that AI can bridge the digital divide by enhancing digital literacy skills such as improving access to online resources and deeper evaluation of these sources. However, the study also identifies risks of AI potentially widening the digital divide if disadvantaged learners are unaware of how AI can aid their academics, lack access to, nor can use these technologies. Overall, AI has the potential to bridge the digital divide between learners, but prevailing issues such as overcoming socioeconomic inequalities, ensuring equitable access to these technologies, and promoting regulated usage of AI tools need to be redressed.

Keywords: Artificial Intelligence, Digital Divide Gap, Higher Education, Learners.

1 INTRODUCTION

The Artificial intelligence (AI) has been continually growing in use and in capability since it was first defined in 1956 [1]. Between 1950 and 1970, the AI industry experienced several significant breakthroughs, most notably the inception of machine learning (ML) technology. The introduction of ML gave AI technology the ability to learn without being explicitly programmed [1] and make predictions through recognising and applying patterns found in datasets [2]. Therefore, it can be more recently defined as

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computing systems that can engage in human-like tasks such as learning, adapting, and self-correction [2], [3].

The latest ground-breaking AI software was released in 2022 in the form of ChatGPT, a conversational agent which utilises several technologies such as generative AI, allowing it to generate human-like responses based on the input the model receives [4]. In less than two years, ChatGPT has had a significant impact on society, especially in education, which is the area of focus for this study. This impact has materialised in several forms, such as the of aiding lecturers by generating course materials, aiding learners by acting as a virtual tutor, and even generating information that is able to bypass plagiarism detectors [5]. Motivated by these various applications, this study aims to delve deeper into AI's influence on education, whether this influence extends to the digital divide gap that exists among learners in higher education institutions (HEIs) [6], and the potential implications of AI's integration into academic environments.

1.1 Problem Statement

The issue of the digital divide can be defined as the gap between individuals or groups at different socioeconomic levels. The differences are in areas such as income and level of education affecting the opportunities of these individuals to use and access ICTs and the internet [7], [8]. Similarly, digital literacy, a concept commonly used to measure the digital divide, can be defined as a person's ability to perform tasks effectively in a digital environment, and to evaluate and apply new knowledge gained from these digital environments [9]. From an educational point of view, such tasks include using basic software such as Microsoft Word, accessing and evaluating online resources for academic writing, and leveraging various online tools to aid in completing assignments [6]. HEI students with the inability to complete such tasks due to insufficient digital literacy skills will find themselves at the negative end of the digital divide in comparison to their peers and risk being susceptible to digital exclusion [10]. This created a problem as the use of ICTs in education, especially in higher education, became a prerequisite [11] to improve the efficiency of all levels of educational tasks in both formal and informal settings [7].

To note, digital divide has three strands, and these represent the three types through which individuals can be discriminated against. The strands are the digital divide of access, digital divide of literacy, and digital divide of quality [12]. While the latter two strands do not emphasise the gap because they are about access but without skill and quality connectivity, the first specifically addresses the issue of access, which particularly speaks to the digital divide gap. As such, with AI technologies increasingly integrated into educational tasks like recording lecture notes, studying, and completing assignments [13], it becomes crucial to examine how AI affects students' digital literacy skills when they enter higher education. This influence includes, but is not limited to, the change in the academic position of the students with strong digital literacy skills versus the students with underdeveloped digital literacy skills because of AI's integration into their educational activities.

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1.2 Research Gap

Throughout the research process, researchers have delved into how AI has been integrated into higher education [13], [14], [15], [16], digital divide in education [7], [11], [10], and AI and the digital divide [13], [9], but as separate concepts. It has been a challenge to find research that problematises these topics in the same breath while also considering the opinions and experiences of students in HEIs. Therefore, this research contributes to filling the gap of inadequate research in this area and adds value to a context beginning to implement practical applications.

1.3 Research Questions and Objectives

Guided by the motivation to problematise the use of AI in the advent of the digital divide challenges among HEI learners, this study was executed with the following questions and objectives in mind.

1. How does AI technology integration in higher education influence the digital divide gap amongst learners?

Furthermore, there are two supplementary sub-questions to help guide this study:

i. How do students know that the technology they are using is enabled by AI?
ii. What tasks are students using AI technology for in higher education institutions?

In response to the research questions posed, the following research objectives were formulated.

2. To examine the influence of integrating AI technology in higher education on the digital divide gap amongst learners.

i. To examine the learners' awareness, that the technologies they are using are enabled by artificial intelligence.
ii. To examine the extent of the utilisation of AI technologies by higher education learners.

1.4 Contribution and Significance of the Research

This study made theoretical contributions to the existing research by advancing the research currently available. This was achieved by creating a better understanding of how the academic abilities of learners are influenced by the integration of AI technologies into their academic work environment. Through this attained understanding, this research can further serve as the basis for future research by HEIs on how AI technology can be leveraged to reduce the digital divide gap amongst its learners. In terms of a practical contribution, the research findings inform learners from similar demographics how their peers have been affected by AI technologies use, particularly in the context of HEIs, and possibly the actions they took in response to its influences.

This inquiry consists of five sections, namely the introduction, the literature review, the research design and methodology, the findings and discussion, and finally the conclusions.

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2 LITERATURE REVIEW

2.1 The Genealogy of AI Technologies

According to Kaul, Enslin, and Gross (2020, p807), the term AI was first outlined by John McCarthy, who further explained that its goal was to be developed as a machine that behaved as if it were intelligent, with intelligent behaviour meaning behaving like a human being [17]. Today, AI is a broad discipline having applications in several fields including, but not limited to, e-commerce, finance, healthcare as well as education [18] – which is the area of focus of this inquiry.

The concept of AI first materialised in the form of an intelligent machine in 1950, six years before McCarthy officially declared the term [1]. The next twenty years following 1950 consisted of several milestone breakthroughs in the AI industry. The first of these breakthroughs was machine learning (ML) which Greenhill and Edmunds, (2020, p. 3) defined as the "*application of sets of algorithms to analyse a given situation, with the ability to learn from feedback about the outcome of the analysis in order to self-adjust and improve accuracy"*. The inception of ML was the first in a line of advanced AI technologies, giving the technology the ability to learn without being explicitly programmed [1] recognise and apply patterns, and make predictions [2]. ML is just one of several subfields of modern AI in today's world. Heinrichs discusses how AI technologies, such as ML, are used to train rational agents before they are released [20]. They can vary significantly in their complexity, ranging from a robotic vacuum-cleaner to an automated taxi [16]. With a general understanding of AI technology discussed, it is necessary to undergo a more in-depth review of literature regarding modern AI technologies which enable the tools learners can use in a higher education context.

2.2 Exploring AI Applications in Higher Education

Before reviewing the current applications of AI technologies in higher education, it is important to first discuss the relationship between AI and higher education. The Editors of Encyclopaedia Britannica (2024) define higher education as "*any of the various types of education given in postsecondary institutions of learning*". AI has the potential to develop all the educational aspects of HEIs, not just for learners but for the teaching staff and administrators as well [21]. It therefore does not come as a surprise to learn that the number of publications of studies based on AI in higher education rose nearly two to three times in 2021 and 2022 compared to previous years [15]. This significant rise in research could have been caused by the widespread use of technology by HEIs to teach learners during the COVID-19 pandemic. Many HEIs have come to accept that AI is the future of education due to its potential to respond to several social and educational needs for students [23].

As mentioned, AI can help teaching staff and administrators at HEIs, for example: the University of Derby introduced a system which monitors student data and can predict when students are likely to drop out, allowing for a timely intervention by either an educator or administrator [23]. However, this paper is focused on the applications of AI in HEIs that can influence the learners' academic performance and experience, and

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therefore these other applications will not be considered in this research. In Zawacki-Richter and others (2019) 150 studies establish that several AI applications are used in education.

2.3 The Digital Divide Concept

The digital divide is the gap between individuals or groups at different socio-economic levels regarding both their opportunities to use and access to information and communication technologies (ICTs), such as computers, and their use of the internet [8]. Within the context of higher education, it involves the adoption option of general components of ICTs in practical use [22], which in the case of this study would include the learning processes of students. Therefore, one can deduce that the abilities of learners to both access and use ICTs for educational purposes will influence the digital divide between themselves and their peers. This raises the question of what determines the ability of learners to use ICTs, introducing the concept of digital literacy into the review.

2.5.1 *The Concept of Digital Literacy*

To redefine the concept, digital literacy is used to measure the digital divide, and can be defined as a person's ability to both perform tasks effectively in a digital environment, and to evaluate and apply new knowledge gained from these digital environments [9]. Using the information discussed above, this definition can further be refined as a person's ability to effectively perform tasks using ICTs and apply new knowledge gained using ICT tools. ICTs have further changed the notion of digital literacy as it has created a new group of disadvantaged people which consists of people who do not have the ability to utilise ICT tools [23]. Belonging to this group of people can lead to digital exclusion as the digital divide amongst peers widens.

2.5.2 Implications of Digital Exclusion

ICTs have become heavily integrated into modern society, in such a way that the digital divide prevents those without access to ICTs or with inadequate digital literacy skills to use ICTs from effectively participating in society [10]. The immediate inadequate access to ICT tools can be an influential prohibitor for anyone trying to improve their social position and intellectual capital [24]. Furthermore, not only does digital exclusion led to a divide in knowledge amongst peers, but it also limits potential opportunities to participate in intercultural networks and shared communications on common subject topics [25].

While emerging technologies are becoming increasingly affordable, when considering the adoption of new ICT applications, countries with different levels of economic output will continue have varying degrees of digital development amongst its citizens [25]. The review will now narrow this thought down and discuss whether it is possible to confirm the existence of a digital divide within the context of HEIs.

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2.5.3 Evidence of the Digital Divide in Higher Education

Racial minorities have been found to be less prepared to use the internet, core computer applications, and digital library resources for academic tasks when entering higher education institutions [6]. This skill gap was measured using the Internet and Computing Core Certification (IC^3) exam used in North America. Mishra et al. (2015) noted that technology terminology, cyber security, use of core operating systems and applications were all areas which racial minorities were found to be lacking on when they enrolled in HEIs. This led to these learners falling behind in their academics compared to their peers as they were unable to access, process, utilise, and exchange information at the same rate [6].

Research has asserted that the higher the level of education amongst learners, the more likely they are to adopt ICTs [26], which should be the goal of HEIs in this context. The increased adoption of ICTs in higher education will also help learners feel more prepared to enter the working world [27]. However, there are claims that HEIs exposing learners to these smart technologies by itself does not carry out their duty of care [28]. It is also about changing the teaching approaches to ensure that learners acquire the necessary skills to succeed in global economies.

As discussed previously, the digital divide is exacerbated by the lack of access to ICTs as well as its use by the learners [23], [24]. As a mitigatory measure, this unequal access to ICTs could be bridged through the subsidisation of these technologies by HEIs, while the issue of unequal use is more dependent on further educational and training programs offered by the institution in the hopes of developing both the learners' awareness of ICTs and their ability to use them [7]. The question of whether the responsibility for bridging the digital divide should rest solely with HEIs or whether learners should also be accountable for their own skills development remains pertinent. This issue warrants further exploration through empirical investigation and serves as the grounds for future research.

2.4 Effects of AI utilisation in bridging the Digital Divide Gap

Research suggests that while AI is a promising technology, it may indirectly exacerbate existing divide (in terms of ICT access and use) between different demographics, helping privileged populations grow stronger while the rest of the population continues to suffer from unequal resource distribution [14]. While the emergence of new AI technologies may help people develop their skills to a higher level, this development will further the gap in comparison to those who do not have the same opportunities [13]. In other words, it can be deduced that AI currently acts as a double-edged sword in the context of the digital divide.

From an educational perspective, learners who are the first to use AI receive an efficient education [13]. On the other hand, learners without the same resources are spending time on finding resources to close the gap, furthering the gap between themselves and their advantaged peers [14]. Certain HEIs may be disadvantaged through the necessary financial means for accessing and maintaining LLMs, which could raise the need for fair access regulations by governmental bodies [29], [30].

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However, research has found cases of the utilisation of AI to potentially bridge knowledge gaps amongst societies. For example, ML technologies have been found to bridge content gaps across different languages, including native languages, by increasing context production to 149% through translation [9]. The transformative power of AI has been recognised by countries such as China, who have set up ambitious initiatives to leverage its abilities for educational equity [13]. Rural education, which characteristically struggles to attract quality educators, has used AI to increase both the quality and quantity of educational resources in these areas [31].

In summary, the impact of AI on the digital divide within higher education is complex. Based on the relatively limited research available, it has the ability to enhance educational experiences while risking the exacerbation of existing disparities [29], [32]. The ability of HEIs to adopt AI technologies is limited by financial constraints, which could potentially require fair access regulations from governmental bodies [30]. Another related issue is that learners who do have access to AI technologies are able to receive a more efficient education, once again widening the gap between themselves and learners who do not have the same privileges [14].

3 RESEARCH METHODOLOGY

In alignment with the main research objective of this study, interpretivism offers a relevant philosophical approach to examining how AI influences the digital divide amongst higher education learners. It places emphasis on the socially constructed nature of reality, proposing that knowledge emerges from shared understandings and cultural contexts [33], which could be crucial when assessing differences in digital literacy amongst learners. The explanatory approach was be followed, explaining the cause-and-effect relationship [34] between the integration of AI technology into higher education and the effects it has on the digital divide gap amongst learners. The study made use of qualitative data to support an inductive research approach. An inductive approach was chosen as it focuses on exploring a phenomenon and building theory based off the collected data [35].

In terms of the research strategy, this study followed the ethnography approach as it collected data on various groups of learners, based on their race, gender, background, and several other factors [36]. This strategy was particularly relevant to the field of information systems, as it captures social dynamics impacting how diverse groups of learners engage with AI tools, unveiling insights into the digital divide in higher education [37]. Data were collected from fifteen students, which were large enough to be considered as a heterogenous sample [38], while at the same time not making the sample too large to the point where the data saturation point is exceeded [39].

Data analysed thematically using the NVivo tool to aid efficiency when working with large amounts of recorded text and facilitating sophistication of analysis [40]. Furthermore, NVivo was used to facilitate the approach to thematic analysis defined by Braun and Clarke (2023). Patterns within the formulated themes were identified. For this study, the ethical clearances were granted by relevant Research Ethics Committees.

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4 PRESENTATION AND DISCUSSION OF FINDINGS

This section presents and discusses the findings obtained from the participants of this study. The findings have been organised into emergent themes, as outlined by Braun and Clarke (2006).

Table 1: profile of the participants

Profile Category	Description
Number of Participants	15 HEI students
Participant ID Format	Codes structured as: *[Institution]-[Group]-[Respondent Number]* (e.g., HEI-A-R01)
List of Participant ID Codes	HEI-A-R01, HEI-A-R02, HEI-A-R03, HEI-A-R04, HEI-A-R05; HEI-B-R01, HEI-B-R02, HEI-B-R03, HEI-B-R04, HEI-B-R05; HEI-C-R01, HEI-C-R02, HEI-C-R03, HEI-C-R04, HEI-C-R05
Population	Higher education students
Geographical Location	3 Universities in the Western Cape, South Africa
Sampling Strategy	Heterogeneous sampling (diverse group)
Participant Diversity	Participants varied in race, gender, and socioeconomic background
Research Approach	Qualitative, interpretivist, ethnographic
Data Collection Method	Open-ended questionnaire
AI Knowledge Levels	Mixed: some with in-depth knowledge, others with limited or no understanding

4.1 The Effects of AI integration on the Digital Divide

4.1.1 Effects of AI on Digital Literacy

As mentioned in the literature review, digital literacy is a concept relevant to this study as a measure of the digital divide and emerged as a major theme during data analysis. The effect of AI on digital literacy, if any, is important to examine as it can directly influence a learner's ability to conduct digitally based tasks [13], therefore altering their position in the digital divide. Such tasks are seen as a necessity in higher education according to a research participant.

"*Regardless of your upbringing, to be a higher education student, one needs some sort of technological device that can connect to the internet since one needs to be able to access course material online.*" [HEI-A-R01]

While participants were divided in their opinion on whether AI has had a positive or negative effect on their digital literacy skills, the results were more positive overall with a student crediting AI with a "*huge increase"* [HEI-A-R02] in their digital literacy since

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adopting AI tools. According to participants, the most common benefit of AI tools was an increase in finding online resources, and an enhanced evaluation of these resources. AI models, such as ChatGPT, have automated the information search process for participants, while simultaneously aiding in finding articles and journals relevant to participants field of research.

"In terms of research, AI has helped me significantly in finding relevant and accredited articles and medical journals which has made finding information a lot easier and more efficient." [HEI-B-R04]

Participants have found AI tools to streamline the information search process through its ability to *"quickly locate relevant sources"* and *"analyse large volumes of text"* with ease [HEI-C-R01]. Through having the ability to analyse large volumes of text, participants have stated that AI has enhanced their personal ability to evaluate online resources by allowing learners to ask questions on sections they do not understand. It is therefore fitting that the interactive nature of AI, such as allowing learners to query retrieved information, has been credited with acting as motivation for learners to adopt these tools as they recognise the ability to better the quality of their education [21].

"I think this is attributed to the change in which I now am able to interact with my academic materials." [HEI-B-R02]

A recurring theme in the collected data is AI allowing participants to redirect their efforts that would have been used on manually analysing large documents to critically interacting with the documents through insightful summaries that serve as a basis for targeted reading and querying. Due to AI empowering its users through the ability to interact with online resources on a deeper level, participants have started to interact with resources that they may have previously ignored due to factors such as resource complexity, resources blocked by a paywall, or issues such as papers written in another language.

"AI-powered tools can translate and simplify complex materials, making them more understandable for non-native speakers and students with learning disabilities." [HEI-C-R04]

In other words, participants have seen a positive change in their level of digital literacy due to AI's ability to make online resources more accessible through improved information search abilities, the enhanced evaluation of online resources, and exposure to resources that may have been previously ignored due to complexity.

"AI tools have drastically transformed the writing process. Now, I can quickly generate outlines, explore different writing styles, and refine content with precision. Grammar and style checks happen in real-time, enhancing the quality and clarity of writing." [HEI-C-R01]

However, there are a few participants who believe that the integration of AI tools into their academics has not had a noticeable effect on their digital literacy. This is mainly due to the participants' infrequent use of AI tools in their academic activities, with one participant stating they have *"never used"* [HEI-B-R03] AI tools.

"Not much, I find with scientific research I find my key points better with manual searches; however, AI may be useful in most normal cases." [HEI-C-R05]

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Only one participant raised concerns over the effect of AI on their digital literacy skills. They raised an interesting point regarding how AI may have had a paradoxical effect on their ability to find and evaluate information.

"In this aspect, it would be apt to say that my digital literacy skills would likely have changed 'negatively' in that AI has become a far more reliable and easier source of digital information." [HEI-B-R02]

It is evident that most participants agree that AI has the potential to enhance various aspects of learners' digital literacy, empowering them with the skills required to improve their position along the digital divide.

4.1.2 The Capability of AI to Bridge the Digital Divide Gap in HEIs

For AI to help bridge the digital divide in higher education, HEIs would need to increase the opportunities of learners from disadvantaged socio-economic groups to use and access ICTs in their academic activities [43]. Several participants believe that AI's ability to help democratise access to resources using ICTs is unparalleled, promoting equitable opportunities amongst all learners if they have access to a digital device and internet connection.

"Students who come from low-income backgrounds may obtain greater benefits of AI compared to students from affluent backgrounds. For instance, a student with extensive financial resources could purchase any textbook, novel, or other literature needed for their course. This would render AI as a supplementary tool, rather than a primary one." [HEI-C-R03]. *"I think AI would have an extremely positive impact on making resources more accessible to students who would not have had this access prior to AI's implementation."* [HEI-A-R01]

AI technologies can promote the use of online resources by disadvantaged learners through transforming the content into a format that is easier to understand and work with regardless of the abilities or backgrounds of these learners.

"…translate and simplify complex materials, making them more understandable for non-native speakers and students with learning disabilities" [HEI-C-R04]

Furthermore, a participant commented how AI-powered teaching platforms, such Khan Academy, can *"evolve understandings of subjects meaning that students working alone will be able to get deep understandings, adding onto understanding gained from teachers"* [HEI-B-R05], acting as a supplementary tool in the learning process. ITS platforms such as Khan Academy or Coursera can also be used for personalised, tailored learning experiences [21].

"It [ITS] is a tool I have seen used throughout my career so far and it seems to help people through their workload." [HEI-A-R03]. *"By providing personalized learning experiences, AI adapts to individual learning styles and paces, ensuring that each student can grasp concepts effectively."* [HEI-C-R04]

Lastly, learners can receive immediate feedback from AI tools that is specific to their work [13]. In other words, learners from previously disadvantaged backgrounds seeking to upskill themselves to the level of their peers will be able to do so independently, without the need for a tutor. Additionally, their questions can be answered instantaneously, significantly accelerating the learning process.

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"Learning to code has become far easier and more accessible. You no longer must pay for someone to teach you the basics over several weeks, you can now get specific answers and help immediately for free." [HEI-A-R02]. *"It also offers real-time feedback and support, helping students overcome challenges promptly."* [HEI-C-R04]

While there is a substantial amount of evidence in the participants' responses that AI can bridge the digital divide by elevating disadvantaged learners to a level closer to their peers, there are potential limitations and considerations that need to be discussed.

A recurring theme in the collected data is that while participants believe AI has the potential to bridge the digital divide gap, its ability to do so is dependent on several external factors. These factors include higher education learners being aware of the AI tools available to them, having access to a device capable of accessing AI tools, and having reliable access to the internet [24].

"I think that the gap could be widened if students are not aware of the capabilities of AI in aiding their studies, or of course if they don't have a device or internet access." [HEI-A-R02]

Another learner believes AI threatens the traditional educational system by *"almost making teachers obsolete"* [HEI-B-R02] by having the ability to tutor or teach a learner in a faster, more personalised manner, especially when compared to higher education lecturers who can teach classes with hundreds of learners.

4.1.3 The Incapability of AI to Bridge the Digital Divide Gap in HEIs

While no participants believe that AI technologies have the inability to bridge the digital divide gap, three of them raised concerns regarding the implications of AI integration into higher education. One participant believes that the use of AI will *"widen the digital divide for sure"* [HEI-B-R01] due to the constant digitalisation of learning resources and environments in today's world. They believe that physical learning facilities such as libraries may become obsolete over time. This could of course negatively affect learners who make use of these facilities, who are typically learners at the negative end of the digital divide as they are not accustomed to using the internet as a source for learning.

"I think that if lecturers continue not to promote or even acknowledge AI tools, it could widen the digital gap that exists between higher education students." [HEI-A-R 01]. *"If you can't adapt you won't overcome. This could both bridge and widen the gap because those who use it will be steps ahead of those who don't…"* [HEI-C-R04]

4.2 Students' Awareness and Knowledge of AI-Powered Tools

Aiming to answer one of the study's secondary research questions, this section will discuss the level of knowledge participants have about the AI tools they are using, and whether they know these tools are powered by AI technologies. Two of the fifteen research participants showed an in-depth understanding of how AI powers a variety of online tools, with another two participants having a basic knowledge of the technology. However, a lack of understanding on how tools are enabled by AI does not seem pose as a barrier to adoption, as fourteen out of fifteen participants have used AI tools. This

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trend reflects broader adoption patterns, with tools like ChatGPT which amassed over a million within its first month of release [44].

"To understand if a tool is enabled by a specific type of AI, such as generative AI, you can look at how it generates content. Generative AI, like the technology behind ChatGPT, creates new content based on the input it receives." [HEI-C-R04]

The remaining research participants indicated that they do not understand how AI technology's function, nor are they able to identify whether a tool is powered by AI or how AI operates within that tool. These participants have admitted that their continuous use of AI-powered tools despite their lack of knowledge is *"kind of dangerous"* [HEI-A-R01] and that they *"probably should know"* [HEI-A-R05] what is happening when they submit a query.

"I do not have a clear understand as to how AI works, I merely understand what it does for me." [HEI-C-R02]. *"I do not think that I could differentiate between types of AI used in different tools."* [HEI-A-R04]. *"…most of these sites always marketing themselves with 'AI' in its description"* [HEI-A-R03].

The participants' lack of understanding of how AI tools' function may also stem from limited exposure to a variety of tools. Two participants noted that they had not felt the need to explore alternative options, as ChatGPT had been effective for their needs, and they were unaware of which other tools were available.

"…ChatGPT has worked well for me… I don't know which other technologies are useful and reliable." [HEI-A-R02]. *"I have only used ChatGPT… I haven't explored much else as I haven't felt there is a need to."* [HEI-B-R04]

The select few of the participants have utilised alternative AI tools and have been able to identify which tools are best suited for specific use cases.

"I know ChatGPT has data restrictions with date etc., but I find Gemini helps give more relevant data analysis while ChatGPT has given fake sources in the past." [HEI-A-R01]. *"I have used Grammarly's AI tool to help correct grammar… All my assignments are essays, so I utilise this tool as a digital proofreader."* [HEI-C-R03]

It could be argued that exposure of a variety of AI-powered tools could be beneficial to learners, as in the case of the participants' responses. Perhaps it could be useful to start gauging the knowledge of learners entering higher education on various AI technologies, such as ML and NLP, and how they work. However, the relationship between HEIs and the use of AI in academics is one of differing opinions, as mentioned throughout this study.

4.3 Academic Tasks Affected Using AI

Exploring one of the study's secondary research questions, this section will analyse which academic tasks have been influenced by AI tools and discuss how learners have been affected using AI. The integration of AI into academic activities by higher education learners seems inevitable, with only two participants opting to continue their tasks manually.

"No, I haven't used AI [for research]. I prefer to just do any research through Google Scholar and formulate my own thoughts." [HEI-A-R04]

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The most prevalent theme found in an analysis of AI's integration into academics was its ability to save participants' time by automating various tasks. Such tasks include streamlining processes such as manually summarising large documents, locating relevant academic articles, and debugging code. Time that would have been spent on these tasks is now being redirected by participants towards interacting with more important aspects of their work.

"*I think it has allowed me to interact with my work on a more critical level. Purely because it erases that need for manual effort.*" [HEI-B-R02]. *"Automation of repetitive tasks, such as data entry and preliminary analysis, saved valuable time."* [HEI-C-R04]

As a result, participants have been able to spend more time on critical thinking, consequently elevating their depth of treatment when completing assignments. For example, a participant is now able to dedicate more time to improving their writing skills by ensuring their content is better organised and by effectively conveying arguments in a precise manner.

"The integration of AI ... has streamlined workflows, making multitasking more manageable and reducing cognitive load." [HEI-C-R01]. *"This is super helpful and allows me to spend more time learning and organising the content.* [HEI-C-R03]

Another participant benefitted from a reduced cognitive load using a previously discussed AI tool, Khan Academy. This tool was noted for its ability to "*evolve understandings of subjects*" [HEI-B-R05] by simplifying content in a manner tailored to the participant's individual learning profile. Such personalisation, offered by VTAs, can greatly assist in studying for exams or addressing questions when a lecturer is unavailable, thereby supporting more effective learning [15]. AI was useful in answering queries specific to the documents they upload, which is particularly valuable for clarifying concepts they find difficult to understand.

"AI-powered flashcards, quizzes, and interactive simulations make studying more engaging and efficient ... summaries, key points, and visual aids, mak[e] complex concepts easier to grasp and remember." [HEI-C-R01]

"[AI use] deepen my understanding and being an extra resource to ensure I fully understand a topic." [HEI-A-R05]

While AI can save time for learners by streamlining tasks, reduce their cognitive load, and enhance existing studying techniques, the participants raised several concerns and considerations regarding the integration of AI into academics. The most common concern amongst participants is the risk of over-reliance on AI tools. Over-reliance on AI technologies for tasks such as essay writing may create a false perception of enhanced digital literacy, placing learners at significant risk of being unable to perform these tasks independently when AI tools are unavailable, such as in the context of final examinations.

"I have witnessed peers copy and paste essay questions into ChatGPT, copy and paste that answer ... and submit the assignment." [HEI-C-R03]. *"Students ... don't actually learn the skill they require to perform tasks when AI is not available."* [HEI-C-R05]

The effects stemming from prolonged over-reliance on AI tools in higher education is of significant concern, and while they were not thoroughly discussed in this study, they form basis for future research.

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"I have become extremely dependent on generative AI with my assignments, which I feel like is a dangerous place to be in. This might affect my brain stimulus in future." [HEI-A-R01]. *"...easy to let these tools do the heavy lifting, which sometimes makes me less inclined to put in the effort myself."* [HEI-C-R04].

4.4 The Relationship between HEIs and the Use of AI in Academic Activities

While not specifically answering a particular research question, this recurring theme in the participants' responses discusses the role that HEIs and lecturers play in an educational environment increasingly shaped by AI integration [15]. Participants are split in their views regarding the part played by lecturers, with one questioning the need for educators entirely and another believing that AI should be used only to supplement lecturers as they are the main source of education.

"I do think AI in some ways threatens the entire ... system ... as it does what they [teachers] do exactly and quicker..." [HEI-B-R02]. *"Using AI similar to Khan Academy can evolve understandings of subjects meaning students working alone will be able to get deep understandings, adding onto understanding gained from teachers."* [HEI-B-R05]

Ultimately, some participants, through firsthand experience, have recognised that AI integration into higher education is inevitable, despite any resistance to change from HEIs. They believe that if lecturers choose not to acknowledge the use of AI by learners and do not promote the sustainable use of these tools, the digital divide gap could widen.

"I think that if lecturers continue not to promote or even acknowledge AI tools, it could widen the digital gap that exists between higher education students." [HEI-A-R01]. *AI is very much not promoted because they are trying to improve our writing skills and critical thinking and don't want students to abuse AI"* [HEI-B-R01]. *"... students could become overly reliant on AI tools, potentially leading to issues with plagiarism or a lack of independent critical thinking skills."* [HEI-C-R04]

In this regard, it is understandable that the faculties' priority may be altering assessment methods to account for learners' use of AI tools. This aligns with Schleicher's (2015) argument that HEIs have a duty of care not only to expose learners to AI tools but also to adapt teaching approaches, ensuring that students develop the necessary skills to succeed outside of university. One participant has recognised these changes claiming *"curriculums are now adjusting to the use of AI technology so therefore your marks will reflect your accurate knowledge regardless of AI"* [HEI-B-R01]. While this may be an effective strategy for reliably assessing the knowledge and abilities of learners, faculties should still consider promoting the sustainable use of AI tools.

5 CONCLUSION

This study finds that AI technology integration into learning activities in HEIs has strong potential to help bridge the digital divide in higher education by improving learners' digital literacy, widening access to online resources, and supporting personalised learning. Many students reported that AI tools enhanced their ability to navigate

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academic content, particularly benefitting those with limited support structures. However, the findings also reveal that a lack of understanding of how AI works limits students' ability to fully benefit from these tools and increases the risk of misuse. This highlights the need for higher education institutions (HEIs) to provide both access to ICT resources and structured learning opportunities focused on AI awareness and responsible use.

The study also warns against over-reliance on AI, which may weaken students' independent thinking, research abilities and exam readiness. AI should therefore support, rather than replace, core academic skills, and both HEIs and learners share responsibility for ensuring ethical, balanced use. Overall, AI can meaningfully contribute to reducing digital inequalities, but its benefits are not automatic. They depend on equitable access to technology, digital skills training, and careful regulation of AI usage.

Future research should explore the experiences of learners from disadvantaged backgrounds, investigating the long-term academic impact of AI use, particularly relating to over-reliance, and examine how HEIs plan to support responsible AI integration in the coming years.

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The Problem of Bachelor's Dissertations in Computer Science, Informatics, and similar Academic Disciplines:
An Experience-based Discussion

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Abstract. The educational or scientific value of Bachelor's dissertations, in Computer Science, Information Systems, Computer Engineering, or similar IT-related disciplines can no longer be taken for granted. Comparing examples from various institutions in various countries, considerable differences have been found as far as the institutional requirements for such dissertations. From personal experiences, these differences do not matter much to those undergraduate students who wish to continue their studies at the same institution, or want to leave the university to enter the world of work after their Bachelor's degree. However, skill comparability problems arise for students who wish to continue their academic career with advanced studies at another university. In such a context, students who already wrote a solid Bachelor's dissertation, will find the transition into the postgraduate (Master's) phase of their studies to be considerably easier, compared to those students who had no prior academic writing experience at Bachelor's level. Many industrially oriented students, who do not wish to remain in academia after having obtained their Bachelor's degree, experience unnecessary frustrations (in some cases even failure) when they are forced against their own inclination to write such a dissertation. This paper presents an experience-based discussion and suggests a conceptualisation of different sub-streams for differently inclined students within the Computer Science Bachelor's curriculum.

Keywords: Bachelor's Dissertations · Computer Science · Informatics · Tertiary Curriculum.

1 Introduction

When comparing Computer Science, or Informatics, undergraduate (BSc) curricula in various countries, and various institutions, a wide variety of requirements for a 'research component', where these curricula are concerned, can be seen. This continuum ranges from the complete absence of any research component to the requirement for a written Bachelor's dissertation which can (in some cases) even reach the quality level of a Masters' dissertation. The ACM/IEEE Computer

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Science Curricula 2023 volume [16, 17] does not mention any requirement for a research component for a Bachelor's degree; however various institutions often design their own undergraduate curricula with contents and criteria that differs notably from the ones outlined in the ACM/IEEE volumes. Even 'outside' the ACM/IEEE curricular system, the situation has always been similarly diverse. For example, before Germany eventually accepted and introduced the Bologna modular system (due to political pressure from industrial lobby groups who wanted to hire younger job-starters) —i.e.: in times when the Master-equivalent Diploma used to be the 'smallest' degree which a German computer science student could get (Master or nothing)— some German institutions (for example the FAU Erlangen) already requested a preparatory dissertation called *Studienarbeit* ('study-work') before the Diploma dissertation, whereas others (such as the RWTH Aachen) did not.

Furthermore, the terminology used to describe the research components in BSc curricula is not always the same across countries, universities, or even institutes or departments within one and the same university. The term, *Bachelor's dissertation*, will be used to capture the concept as well as the product of an undergraduate 'research component', which is a suitably limited research-based study conducted in a student's fourth academic year under a mentor's supervision. In the sections that follow, the role of the Bachelor's dissertation in Computer Science or similar IT-related fourth year, is strongly informed by the long-term personal experiences in these matters of the authors.

To avoid any misunderstandings, for the remainder of the discussion, the terms 'Computer Science' and 'Informatics' will be used interchangeably [7, pp.2-3]. Moreover, it should be emphasised that this evidence-based discussion-contribution to the SACLA conference is informed mainly by long-term personal experiences within a world-wide web of experienced and highly qualified academic colleagues — though not yet a fully-completed research-study at this point in time.

To provide some contextual information, the *typical* structure of (and articulation of a student through) a *typical* BSc Computer Science degree programme will be provided. Several illustrative examples of Bachelor's dissertations which Computer Science students from various countries and institutions have written, in which some kind of 'research component' was included (perhaps optional, perhaps mandatory), will be reviewed. Thereafter, the academic requirement for a Bachelor's dissertation (at least in those institutions in which a 'research component' is compulsory), which is becoming increasingly problematic in the *diversified academia* of today, in which cohorts of students are now socio-culturally far less homogeneous than they used to be half a century ago, will be considered. For some of these students, even a mini-dissertation might already be 'not do-able', other students (with other ambitions) might still feel dissatisfied, even by quite substantial pieces of written work. Moreover, in addition to this socio-cultural dilemma of a strongly diversified student cohort (with widely differing plans and ambitions for their own individual futures), comes the technological problem of Generative Artificial Intelligence (for example, ChatGPT — known amongst

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many students as "Ch**e**atGPT"), which can automatically generate chunks of text so strikingly similar to any genuine human-written Bachelor's dissertation, that the submission of such a piece of 'work' for purposes of assessment (marking or grading) is becoming less and less indicative of an individual student's actual academic capability.

2 Overview of Bachelor's Dissertations in Various Countries

Globally there is variation in the placement and requirements for obtaining a Bachelor of Science (BSc) degree in Computer Science, or similar disciplines. The curricular structure, and therefore the number of years it takes to complete a Bachelor's degree, varies from country to country, and from institute to institute, with implications for the placement of the Bachelor's dissertation (if any) within a curriculum. Bachelor degree structures the world over, typically follow one of two scenarios: the one requires students to complete four years of study before they graduate with a Bachelor's degree; the other requires three years of study [2].

The three-year Bachelor's degree does not include a Bachelor's dissertation. In some countries (for example, South Africa), it is followed by an Honours degree which is considered to be an entry-level postgraduate degree before the Master's studies. Other countries, allow students to begin a Master's project immediately after a three-year BSc degree, for example McMaster University in Canada. If the students are required by local rules and regulations to write any Bachelor's dissertation, then this will happen either in the 4th year of the Bachelor's curriculum, or as part of the Honours degree in countries who have implemented the Honours model.

As can be seen, there is quite some variation in the requirements for obtaining a four-year BSc or BSc Honours degree in Computer Science or closely related academic disciplines. These variations may be prescribed by individual, departmental, institutional, or governmental policies and/or judgments. For example, some universities in some countries require their prospective Bachelor students to write and submit quite a sophisticated Bachelor's dissertation, that is almost the length and quality of a Masters dissertation [26], whereas other universities in other countries do not require such an academic product, and award the degree solely on the basis of passing course modules. Yet other universities, follow a 'middle of the road' approach, in which the candidate must submit a shorter Bachelor's dissertation, either alone or as a member of a project group, on a rather small topic — perhaps a short literature review essay, perhaps some computer programming or software development.

From personal conversations with colleagues in various countries, some kind of Bachelor's dissertation must be produced by the candidates before graduation. Some universities keep these dissertations confidential (for internal assessment and use only) whereas other universities may also publish them online (after assessment and correction) via their libraries, in a similar manner as done with

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their Master's or Doctoral dissertations. Most of those Bachelor's dissertations, presented below, were kindly provided by international colleagues via non-public e-mail communications.

By contrast, it is worth noting that in November 2023 one of the several universities in Prague, publicly announced the *abolition* of Bachelor dissertations altogether (which until then had been required to be written) simply because the institution was no longer able to cope with the flood of plagiarism cases in combination with the students' deliberately fraudulent misuse of Generative Artificial Intelligence service-software as convenient short-cuts on their paths towards their Bachelor degrees [12]. From this phenomenon it can plausibly be inferred that many (though not all) students at large universities, have completely lost all ambitions towards any form of what used to be called a 'scholarly life'. All they desire is the piece of paper that has the prestigious words 'Degree' or 'Diploma' printed on it, and they want to obtain it as quickly and easily as anyhow possible, refer to [32] for comparison. However, all the phenomena and variations mentioned in this section have implications, both for those students who wish to continue with their studies to a Master's level (perhaps at the same university from which they obtained their BSc degree, perhaps elsewhere at another university), as well as for those students who wish to obtain their BSc degrees only in order to become immediately employable in the world of work.

3 The Dilemma of Diversification

The non-classical academic landscape, characteristic of the present era, was already shaped approximately half a century ago, but the process of coming to terms with it, remains unfinished.

> " *In the systems and institutions of mass higher education standards become variable, differing in severity and character in different parts of the system or institution, appropriately so since both system and institution have become holding companies for quite different kinds of academic enterprises. In institutions of universal access there tends to be a different criterion of achievement: not so much the achievement of some academic standard, as whether there has been any value added by virtue of the educational experience*" [32, p.13].

Accordingly, the variations in the curricular structures and qualification requirements, as well as the levels to which the students are expected to progress within the various Computer Science curricula, cannot be separated from the purpose —nor the concept— of a Bachelor's dissertation within those contexts. Based on the professional experiences of the authors, these variations also make it difficult for students to 'articulate' (move) between different institutions with different Bachelor's dissertation requirements. In particular, problems can arise for those students who wish to continue with Master's studies after their Bachelor's or Honours degree elsewhere, when their lack (or insufficient quality) of a Bachelor's dissertation might possibly result in a feeling of shock when these students

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are confronted with highly demanding Master's requirements at the other institution. Of course the aforementioned observation does not state in any way a general rule. In fact, one of the authors, had gladly 'escaped' from the previously mentioned *Studienarbeit* by 'moving over' from FAU Erlangen to RWTH Aachen after having obtained the 'half-time' studies certificate (*Vordiplom* Pre-Diploma) in Erlangen — having been able to write a reasonably acceptable Diploma thesis nonetheless.

Another relevant point in case is that not all students wish to continue studying beyond their Bachelor's degree [9] [32, p.46]. For those students the completion of a Bachelor's dissertation, if required, does not necessarily enhance their employability in industry, and is not always a joyful experience just for the sake of 'doing something interesting' in its own right (regardless of any subsequent utility). Indeed, based on personal experiences, many of those students find it frustratingly difficult to successfully acquire their Bachelor's degree from institutions at which a compulsory 'research component' is implemented rigorously at highly demanding levels of quality (i.e.: technical or scientific contents) and/or quantity (i.e.: duration of the research project or dissertation's number of pages), even though a flurry of self-help-books on *How to write a dissertation* has been thrown onto the commercial book market by various authors during the past decades, specifically for those helpless students [34]. Experiences of supervising at university, has highlighted that there are cases in which students successfully passed the usual Honours course-work modules but failed to obtain the Honours degree only because of their inability to complete a meaningful Honours dissertation project.

This dilemma is a consequence of more than 150 years of 'transformation' of the universities all over the world from small Humboldt'ian *republics of scholars* in the mid-19th century to mass-producers of technically skilled 'white-collar labourers' for the national or international economy [8], and was the main motivation for considering and discussing the inclusion or exclusion of the Bachelor's dissertation into the fourth year (or Honours year) of a BSc Computer Science curriculum in this paper. On the basis of the considerations outlined above, the dilemma can now be summarised as follows:

- A too lax interpretation of the 'research component' requirements in study-year 4 can result in frustration of under-prepared Master's students at some later point in time, whereas a too strict interpretation of the 'research component' requirement can lead to the immediate frustration (or even failure) of those students who are not planning to continue their personal careers towards higher postgraduate academic levels.

The examples of different Bachelor's dissertations in the next section (though not 'systematically' sampled and not 'statistically representative' in a strict social-scientific manner), already suffice to convincingly illustrate the main points of concern.

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4 Evidence from International Examples

The evidence provided in this section was provided by academic colleagues from universities located in Asia, Europe, North-America, and South-America, illustrated in Figure 1. The 24 Bachelor's dissertations collected adhere to local institutional regulations, only considering open source examination documents and not confidential student dissertations. Personal correspondence with academics within the identified countries selected and shared dissertations that showcase academic diversity within their field of expertise on an international scale.

The important factor of *time* is not immediately evident from the completed work as such. Some institutions force their BSc students to finish their BSc dissertations within one academic year, other institutions are more lenient with the timing and allow their BSc students to continue with their work in a more open-ended fashion 'until it is done'. When comparing the quality of a 'long' piece of work with the quality of a 'short' piece of work, the institutional time constraints might have played their role in those differences, too.

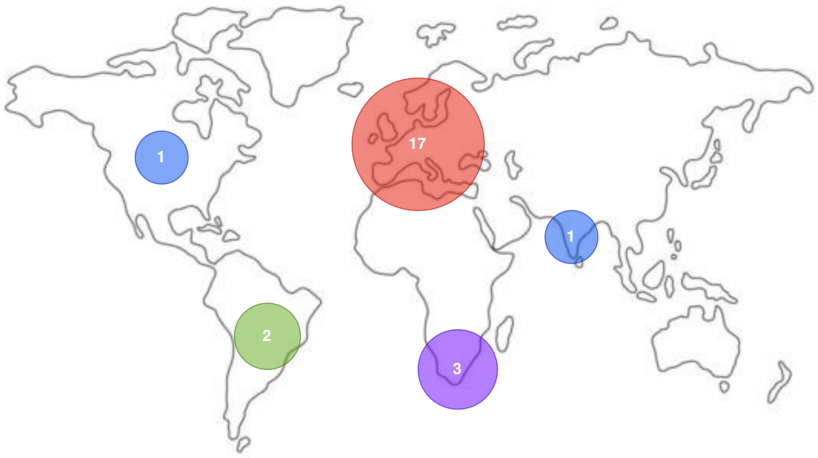


Fig. 1. Visual depiction of examples received for analysis

4.1 Brazil

Two Brazilian examples were analysed. The examples showed a focus on either a more technical or literacy stance. The analysed examples focused on the following:

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- a single-authored Bachelor's project report of just above *20 A4-size pages* on the topic of *Real-Time Internet Traffic Analysis*. This work to a large extent was a *wordy essay* and does not delve deeply into the formal or technical details of the chosen topic [29];
- a single-authored Bachelor's project report of approximately *30 A4-size pages* on the topic of *Controller Modelling*. This work largely consisted of practical-experimentation, while including descriptions and discussions regarding the experiments conducted [33].

4.2 Germany

Germany's examples focused heavily on experimental comparisons between various academic interests in different fields, such as programming languages, and compiler construction. The following five examples were analysed:

- a single-authored Bachelor's dissertation of approximately *70 A4-size pages* (plus Bibliography and Appendix) in the field of *Compiler Construction* of such scientific and technical depth that it might possibly have been accepted as a Master's thesis by other institutions of tertiary education [15];
- a single-authored medium-size Bachelor's report of approximately *30 pages* (plus bibliography) about a technically non-trivial project in the intersection area of *Formal Languages and Software Engineering* wherein some new IDE support for some features of the programming language 'Effekt' was implemented [22];
- a single-authored Bachelor's project dissertation of approximately *40 A4-size pages* in the area of *Software Engineering* [25], focusing on considerable technical difficulty. Elements from the domain of compiler construction (especially syntax trees) were transferred into the domain of software engineering for a better handling of software product lines;
- a rather brief but nonetheless technically solid single-authored mini-thesis with approximately *20 pages* in the LNCS format (plus appendices) on the topic of *Syntax Parsing* wherein the student automatically extracted and composed control flow graphs (CFG) from given JavaScript programs [27];
- a single-authored Bachelor's dissertation of almost *80 A4-size pages* (albeit with 1.5 line gap size, hence shorter when normalised to gap-less line spacing) on the topic of *Real-time Set Editing in a virtual production environment* with an innovative interface. The underlying project work was carried out very diligently with a thorough third-party evaluation of its results by numerous IT-industrial cooperation partners [28].

4.3 India

From India an elaborate single-authored Bachelor's dissertation of approximately *60 A4-size pages* on the topic of *Digital Education with MOOCs* was considered. This example of a Bachelor's dissertation already approaches an MSc level of quality in at least some of its parts, with in-depth discussions of ample technical details [30]. The detail demonstrated in this dissertation considered academic and theoretical understanding.

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4.4 Netherlands

The examples obtained from the academics situated in the Netherlands were more technical, while still showing literary connection. The three analysed examples were:

- a single-authored Bachelor's project dissertation of approximately *40 A4-size pages* on the topic of *System and Network Security*. This work is rich in technical details and shows results of several non-trivial experiments [1];
- a single-authored Bachelor's project dissertation on the cryptological topic of *TLS Protocol Vulnerabilities*. The main part approaches almost *50 A4-size pages* (plus approximately 20 appendix pages with program code and other technical details). In this BSc dissertation bibliography, more than hundred literature sources were listed [19];
- a single-authored Bachelor's project dissertation of approximately *40 A4-size pages* on the topic of *Artificial Intelligence*. A technically detailed study and presenting results from several non-trivial experiments [24].

4.5 South Africa

The examples analysed from South Africa depicted the completion of the fourth-year of study, as part of a BSc-Honours degree. The main focus of the analysed examples was on understanding the research concepts through experimentation and literary connections. The examples analysed were:

- a single-authored BSc-Honours dissertation of approximately *65 pages* (including the literature references and several technical appendices) in a layout that is similar to the format of the well-known LNCS. With a topic on *Multidimensional Tetrad Graphs* [4], and with a quality and technical depth comparable to the sample. This Bachelor's dissertation has obtained a thorough understanding of the chosen area of work at a considerably high level of symbolic formality;
- a single-authored BSc-Honours dissertation of approximately *50 pages* (including the literature references and several technical appendices) in an LNCS-like format [23], focusing on *Enhanced Entity Relationship* models (EER), and with considerable depth in mathematical formalisms, reaching a quite thorough understanding of the chosen topic;
- a single-authored BSc-Honours dissertation in *Algebra* with a topic closely related to the field of *Theoretical Informatics*, namely: an investigation of the truth of the famous *Collatz Conjecture* when it is considered in number systems other than the Natural Numbers [31]. With approximately *40 pages*, densely packed with formulae and proofs, this Bachelor's dissertation is arguably of considerably higher quality and conceptual depth than many other Bachelor's projects seen in the more applied or practical branches of Computer Science.

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4.6 Spain

The example analysed from Spain consisted of a single-authored Bachelor's dissertation of approximately *60 A4-size* pages on the topic of *Software Engineering for Information Repositories*. Though to a large extent 'wordy' in its presentation. It focused on technical software engineering work, carried out before this Bachelor's dissertation could be written [6], and is of substantial size. Not to be under-estimated in its technical difficulty.

4.7 Sweden

The Swedish examples were the only examples that included a range of one to multiple authors. This allowed for the combining and comparing of components dependent on an overall concept. The four examples analysed were:

- a single-authored Bachelor's dissertation of approximately *40 A4-size pages* in the area of *Automated Software Engineering* (ASE) whereby a data processing engine called 'Elasticsearch' and the text generator 'Lina' were combined and experimentally evaluated [10];
- a **double**-authored Bachelor's dissertation of approximately *65 A4-size pages* in the classical field of *Algorithms and Data Structures*, whereby **two** project students together implemented and analysed a new dynamic routing algorithm [11];
- a single-authored Bachelor's dissertation of approximately *30 A4-size pages* in the area of *Artificial Intelligence*, whereby the affects of an AI agent's 'artificial personality' on its users were analysed. For this purpose the student used an already existing template for AI agents and programmed the further details of the agent's artificial 'personality' into the template [18];
- a **multi**-authored Bachelor's dissertation of approximately *50 A4-size pages* in the difficult area of *Quantum Computing*, whereby **six** project students jointly optimised a QC simulator by means of data compression and GPU acceleration [20].

4.8 Switzerland

The examples gathered from Switzerland were very experiment focused, emphasising the need for in-depth theoretical and statistical content. Compared to Sweden having authors contributing to the same output, two of the examples from Switzerland had the same overall topic, but had separate research outcomes. The four examples analysed from Switzerland were:

- a very short single-authored Bachelor's project report of approximately *20 A4-size pages* (plus a few appendix pages) on the topic of implementation and evaluation of different processes-to-node mapping strategies for the HAEC platform in *High Performance Computing* [3]. This Bachelor's dissertation showcased that the requirements are not necessarily standardised as far as length or size are concerned. Technically, however, this quantitatively shorter work appears to be of more theoretical depth rather than literary;

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- a single-authored Bachelor's project dissertation of approximately *50 A4-size pages* (bibliography included) in the area of *Operating Systems for High-Performance Computing*, whereby frequently occurring patterns of computation were identified and analysed with the aim of exploiting them for more efficient scheduling and, hence, better overall throughput in the statistical average case [13];
- a single-authored Bachelor's project dissertation of approximately *40 A4-size pages* on the topic of *Energy Consumption in High Performance Computing*. This example shows to a large extent empirical work with many experimental observations though not many theoretical considerations [14];
- a single-authored Bachelor's project dissertation of approximately *40 A4-size pages* (including appendices) in the area of *Parallel Programming* with non-trivial loop optimisations and run-time experiments [21].

4.9 United States of America

Last but not least, from the USA, the example was rather short and heavily focused on literature. This example was a single-authored Bachelor's project report of approximately *25 A4-size pages* (notably with quite wide gaps between the lines — hence perhaps equivalent to 15 pages with normal line spacing) on the topic of *Medical Image Processing* algorithms. This Bachelor's mini-dissertation is in most of its parts a 'wordy essay', though it has an additional appendix in which some technical-implementation details are shown [5].

4.10 Other Possible Cases

As previously mentioned, there are many universities (or other tertiary education institutions) where no Bachelor's dissertations are written at all (course-work only), or where written Bachelor's dissertations as examination documents are kept confidential (for internal use only). Such disserations were excluded from the analysed examples to adhere to institutional regulations. This limit poses no obstacle against the analysis conducted, because all the foregoing examples have already sufficiently illustrated the wide range of institutional possibilities in matters of BSc dissertations.

5 Interpretation of the Observations

The review of the 24 Bachelor's dissertations from several countries on all continents, in the previous section has shown a *wide variety in common academic practice*, from single-authored work to group-work with several co-authors as well as from small semester projects (described in reports of approximately 20 pages) to large Bachelor's dissertations with qualities similar to the qualities of Master's projects (and written reports of more than 70 pages in size). All this variety can be observed in a wide range of Computer Science related themes and

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topics from algebraically formalised Theoretical Computer Science to practical and experimental Algorithmics, Computer- and Software-Engineering, etc.

Consequently, the *meaning* of the phrase "Bachelor's dissertation" *cannot be taken for granted as 'universally self-understanding'*. The actual qualifications (knowledge and capabilities) of a graduating BSc-student might have to be individually re-assessed, on a case to case basis, whenever a student 'migrates' from tertiary education into the world of industrial IT-work, or from one academic institution to another one in pursuit of advancing computer-scientific scholarship to the next academic level.

6 Discussion, Conclusion and Outlook

By comparing Bachelor's dissertations in Computer Science, or closely related academic disciplines, notable differences have been found between them in size (length) and quality (scholarly or technical depth). These differences appear not only between the different educational systems of different countries, but also between different universities (or similar institutions of higher education) which operate under the umbrella of the same national or regional educational system within one country. Moreover, there are also numerous universities where no Bachelor's dissertation is required at all for the purpose of obtaining a Bachelor's degree in Computer Science and related academic disciplines. Whereas these differences do not matter very much to those undergraduate students who wish to continue their academic studies at the same institution from which they also obtained their Bachelor's degree, or who want to leave the university for good, *competence comparability problems* might possibly arise in those cases in which students wish to continue their higher academic studies elsewhere, at another university, where Bachelor's degrees are awarded under possibly quite different conditions and requirements.

In such a context the authors have repeatedly (though not always) experienced at their own institution that those students, who already wrote a solid Bachelor's dissertation, have a 'smoother' transition into the Master's phase of their computer-scientific studies, compared to those Master-students who had no prior exposure to academic writing at all. From the perspective of industrially oriented undergraduate students, who do not wish to remain in academia after having obtained their Bachelor's degree, the writing of a Bachelor's dissertation is frequently perceived as merely a tedious and frustrating ('boring', 'useless', 'time-wasting') academic 'finger-exercise' which does not seem to 'add value' to their envisioned professional futures: This, too, is an experience which has repeatedly been observed by the authors on numerous occasions at their own institution. The *socio-cultural diversity of the cohorts of students* in tertiary education during the past fifty years since the times of [32], including the students' widely varying plans for their individually envisioned futures, appears to be one of the main roots of the above-mentioned dilemma concerning the inclusion (or the abolition) of Bachelor's dissertation requirements into (or from) contemporary BSc curricula in Computer Science, and their closely re-

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lated academic disciplines. Hence, the problematic question arises: *Which kind of BSc-curriculum is 'best aligned' to the future plans of each of the large social groups of BSc undergraduate students?*

- An undergraduate curriculum *without any* Bachelor's dissertation requirement at all might seem to be most beneficial for a large cohort of BSc students who do not have any ambitions for higher education at the Master's level, and who wish to leave the university immediately after having obtained their BSc degree. There are of course professional roles in the Information Technology industry, such as 'Project Manager' or 'Director of Technology and Engineering', for which a Master's degree and sometimes even a Doctoral degree is required. Furthermore, a 'no-dissertation-solution' might also look very tempting for a number of financially under-funded and academically under-staffed institutions which can no longer 'scientifically' interact with large groups of enrolled BSc-students in the era of tertiary mass-eduction.
- An undergraduate curriculum with very strong, strict and rigorous Bachelor dissertation requirements for 'long' and 'deep' pieces of written work might possibly appear considerably more attractive and satisfactory for scientifically ambitious students who are 'aiming higher' and who tend to genuinely enjoy scientific knowledge for its own sake regardless of any practical 'utility' considerations. This group of students, however, from which the next generation of lecturers and professors will most likely get 'recruited' and which is thus highly important for the future continuation of academia itself, is comparatively small in numbers nowadays [9]. For a young member of this minority group, a Bachelor's dissertation of very high quality might in some cases perhaps even lead to a first local or regional conference publication (though that is not an explicit educational goal of the BSc degree) which may subsequently place such a BSc student onto a strong academic path, already at a very young age.
- Any 'one-size-fits-all' approach to the BSc degree, as a somewhat weak compromise between the two above-mentioned extreme possibilities, might perhaps request every BSc student to write a small and not-too-complicated mini-dissertation of perhaps 20-30 pages length — perhaps alone, perhaps as a member of a BSc project group. Such a solution will perhaps satisfy neither the industrially oriented nor the scientifically oriented undergraduate students in the cohort, though for some still-undecided students, who are not very highly gifted, and who are still 'drifting along' without a general plan for their own future, such a not-very-challenging mini-dissertation might perhaps be 'just right' or 'good enough'.

Different types of Tertiary Education institutions (e.g.: 'classical' universities, vocation-oriented institutions, etc.) might well find *for themselves* different answers to the question above, though the fundamental fact remains, more and more vocation-oriented students are entering the 'classical' scientific-philosophical universities, which nowadays present themselves everywhere and evermore as producing 'employable' graduates for the national economy. At the same time,

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most of the vocation-oriented institutions want to 'upgrade' their rank to 'university' status for the sake of a competitive reputation and customer-attraction in an increasingly market-oriented, and market-driven world as a profitable 'education business'. Consequently, *no* type of tertiary education institute will be able to entirely avoid the above-mentioned dilemma of the socio-cultural student-diversity on its campus these days.

With ever more undergraduate students entering a Computer Science Bachelors curriculum in the current era of mass-education, the authorship *type* of Bachelor's dissertations becomes increasingly important, in particular when the students' cohort size per academic year exceeds a small academic department's personnel capacity to individually supervise too large numbers of registered students.[1] Increasing the number of co-authors for one Bachelor's dissertation may 'lighten' a small academic department's supervision load, although experience has shown that in any group-work there will almost always be 'the one' student who luckily reaps the harvest of the other students' efforts.

In the authors view, only a *diversification of the BSc curriculum with more internal choice* for the students (rather than a mediocre 'one-size-fits-all' prescription for everybody) can do justice to today's intrinsically diversified cohorts of undergraduate students in the information- or computer-scientific academic disciplines. One such option for the students, which would make a lot of sense in today's situation, could well be: *either* a Bachelor's dissertation of substantial length and theoretical depth, *or* some meaningful *alternative extra-activities* (whatever those might be in various local circumstances) that are approximately time-equivalent to the writing of a substantial computer-scientific Bachelor's dissertation — however *no* mediocre 'something-in-between'. Confronted with such a choice, the alternative branches would *differ in quality but not in 'reputational value'*, the undergraduate students would truly have to take ownership and responsibility for their own career paths instead of passively (and, alas, in many cases: joylessly) drifting along with whatever some professors have already decided and prescribed. Moreover, with such a BSc curriculum design, it is conjectured that the numbers of worthless AI-generated 'cheat dissertations' could be significantly reduced, as highly motivated and scientifically inclined students would not have many psychological motivations for 'cheating themselves out' of doing something which they themselves have pro-actively chosen to do for the love of doing it.

The purpose of this paper is to encourage and continue the discussion into Bachelor's dissertations before continuation into the Masters and Doctoral studies.

[1] For comparison, the Technical University of München (TUM), to highlight just one of many internationally well-known examples, has approximately *ten times more* Full-Professors in Computer Science than the authors own institution, *although* the TUM has all-in-all *fewer* students (approximately 53'000 in 2025) than the authors university (with approximately 56'000 students in the year 2025), resulting in a considerably better staff-to-student ratio.

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Virtual Reality as a Method for Training Undergraduate Computer Science Students in CAT6 Network cable Termination: A Pilot study

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Abstract. Traditional IT education often struggles to bridge the gap between theoretical knowledge and practical application, particularly regarding hardware tasks like network cable termination. This pilot study evaluates an immersive Virtual Reality (VR) application, developed for Meta Quest 3, designed to train undergraduate Computer Science students in CAT6 cable termination. Using a mixed-methods approach, the study measured the usability and user experience (UX) of the application's practice mode among fourth-year Honours students. Performance metrics, including task success, error rates, and time per session, were integrated into a Single Usability Metric (SUM), alongside the System Usability Scale (SUS) and Net Promoter Score (NPS). Results from the pilot indicated a SUM score of 61.72% and an average SUS score of 70, suggesting marginal usability with significant room for improvement. Qualitative observations revealed that while students valued the immersive environment, they faced challenges with controller-based interactions and a lack of prior practical experience. Participant feedback led to several iterative improvements, such as adding instructional videos, cable labelling, and a "redo" functionality for wiring tasks. These findings highlight the potential for XR technologies to provide accessible, low-cost training solutions in technical education. Future work will focus on testing the mobile version and assessment modes with larger sample sizes to further validate the system's effectiveness in closing the practical skills gap.

Keywords: Virtual Reality, Network Cabling, Computer Science Education, Usability, CAT6 Termination.

1 Introduction

Network cabling serves as the physical backbone of modern digital communication, allowing for the essential connection of multiple devices within a network. Regardless of the specific installation environment, the precision of these physical connections is important; incorrectly installed cables can lead to significant network degradation or total failure [1]. Within the installation lifecycle, termination, which refers to the process of attaching connectors to the ends of a raw cable, is a critical skill that enables

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hardware like routers, switches, and workstations to interface with the broader network [2]

For students within the Department of Computer Science and Informatics at the University of the Free State, these concepts are introduced in a compulsory third-year Networking module. While the module successfully conveys the theoretical underpinnings of networking and provides virtualised environments for software-based practicals, it faces a significant bottleneck regarding physical hardware skills. Due to constraints in laboratory space, limited time for individual instruction, and the recurring cost of consumable resources like CAT6 cabling and RJ45 connectors [3–5]. This causes many students to graduate without ever having used a crimping tool.

To address this pedagogical gap, an immersive Virtual Reality (VR) application was developed to simulate the three core phases of cable termination: wiring, crimping, and testing. Utilising the Meta Quest 3 head-mounted display (HMD), the system provides a 360-degree interactive environment [6] where students can master these skills safely and at a lower long-term cost than traditional labs.

This paper details a pilot study designed to evaluate the initial usability of this system and its potential to supplement existing curricula.

2 Background and Rationale

The shift toward digital and immersive learning environments is driven by the realisation that traditional lecture-based methods are increasingly inadequate for preparing IT professionals for modern industry demands. Students require hands-on experience to solidify theoretical concepts, yet institutions face rising student numbers and shrinking budgets. Extended Reality (XR) has emerged as a compelling solution, offering a repeatable, accessible training environment that eliminates the need for expensive physical equipment and consumables.

While existing literature has explored XR for general education (e.g., Kexin Yang, [7] and Li Keqin [8]), there is a notable scarcity of applications specifically targeting networking hardware. Previous systems, such as those by Bradley et al. [9] have focused on Augmented Reality (AR) to guide students through physical rack configurations or VLAN setups. However, these systems often require students to be physically present in a lab with expensive switches. This research differs by focusing on a fully immersive VR environment that simulates the termination of Unshielded Twisted Pair (UTP) cabling. UTP and shielded twisted pair (STP) are terminated in the same way and are the most common cable types used for short-distance networking [10]. This approach allows students to practice T568A or T568B wiring standards anywhere, using a mobile or immersive platform. This should assist in addressing the problem that not all students have access to practice network cable crimping, and a lot of them might have only one chance [11, 12], as is the case with some modules at higher education institutions.

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2.1 Technical Standards: T568A vs. T568B

An important component of this research was ensuring the simulation accurately reflected industry-standard wiring configurations. In South African telecommunications and networking environments, both the T568A and T568B standards are utilised, though T568B is more prevalent in modern commercial installations. The VR application was programmed to randomly assign one of these two standards to the user during the practice session to ensure they could not rely on one method only [13, 14].

Properly distinguishing between these standards is more than an academic exercise; crossing them between ends of a cable results in a crossover cable, which, while useful for older peer-to-peer device connections, is often incorrect for modern infrastructure [10]. By allowing students to identify the colour-coded sequences (Green/White, Green, Orange/White, Blue, Blue/White, Orange, Brown/White, Brown) within the 3D space, the system aims to build the muscle memory required to handle physical UTP and STP cables, where visibility and wire gauge can be challenging to manage.

3 Methods and Materials

3.1 Methodology and Sampling

To complement the evaluation of the VR application, a mixed-methods methodology [15] was used. Quantitative data were collected through task success rates, error counts, and time-on-session metrics, supplemented by the System Usability Scale (SUS) [16], Net Promoter Score (NPS) [17] and expectation measure [18]. Qualitatively, feedback was gathered through direct observations and participant comments during the sessions. All metrics were then combined into a single usability metric (SUM) [19] to provide an overall look at the usability and UX of the application.

The pilot study involved four fourth-year Honours students from the University of the Free State. These participants were selected via convenience sampling, as they had already completed the theoretical networking module and could provide informed feedback on the simulation's accuracy. One participant's data was excluded from the final analysis due to severe cybersickness (CS) early in the session, leaving a final sample of three.

All participants had the opportunity to book a session with the researcher (MK), which allowed more flexibility with sessions. Participants arrived and were briefed before completing an informed consent form. After this, the testing procedure outlined in the following section was followed.

3.2 Setup and Hardware

Sessions were scheduled based on each of the participants' availability to accommodate them. Participants were immersed using a Meta Quest 3 HMD. Each session began with a briefing and the completion of informed consent forms. To maintain hygiene, headsets were cleaned with 70% alcohol wipes between users. The simulation took place in a controlled usability lab and in the virtual practice room featured a To-Do List on a

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whiteboard and a workstation equipped with virtual cables, RJ45 connectors, wall boxes, and crimping tools.

The VR application consisted of a room where the students got the tasks they needed to perform (see Fig. 1). These tasks were:

- Task 1: Select the boot option and insert 2 boots on any network cable
    - Sub Task: Boot 1
    - Sub Task: Boot 2
- Task 2: Select the RJ45 option and arrange the wires for the RJ45 Ethernet cables according to T568B wiring standard (The wiring standard changes randomly to either A or B spec)
    - Sub Task: RJ45 grab the cables for connector 1
    - Sub Task: Terminate cables for connector 1
    - Sub Task: RJ45 grab the cables for connector 2
    - Sub Task: Terminate cables for connector 2
    - Sub Task: RJ45 grab the cables for connector 3
    - Sub Task: Terminate cables for connector 3
- Task 3: Select the wall box option and arrange the wires for the RJ45 wall box according to T568B wiring standard (The wiring standard changes randomly to either A or B spec)
    - Sub Task: Wall box
    - Sub Task: Terminate cables
- Task 5: Test/Evaluate your connections
- Task 6: Press the tutorial button on the controller
- Task 7: Locate the restart button and
- Task 8: Restart the simulation

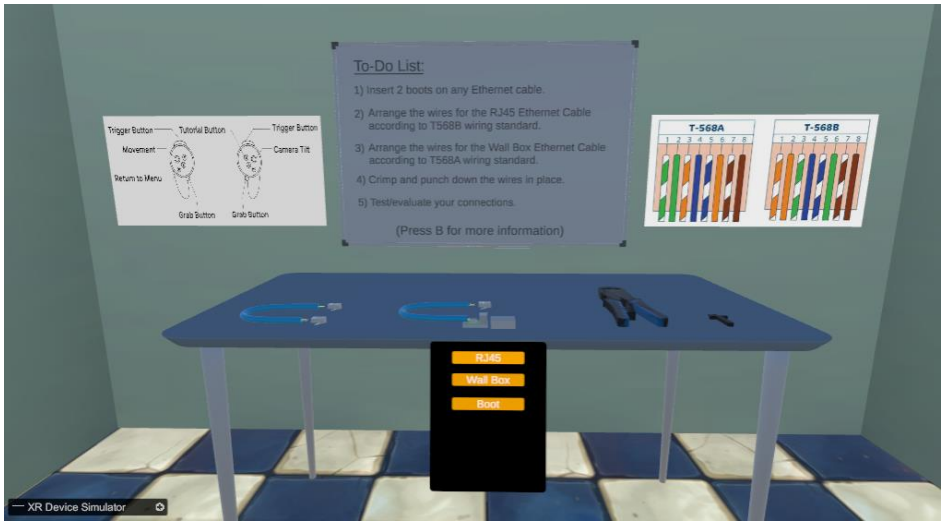


Fig. 1. VE Layout and Setup for Practice mode

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From the room seen in Fig. 1, the user could view all the controls, see the different crimping specifications and see the list of tasks. The first step involved applying the boot to the cable after the boot was applied; the connection of the cables could be done. To do this, the simulation zoomed into the cable termination point, where the participant could select the point of the cable and allocate it to the correct position using the controller (Fig. 2). This was done to allow the user to easily see the cables and manipulate them.

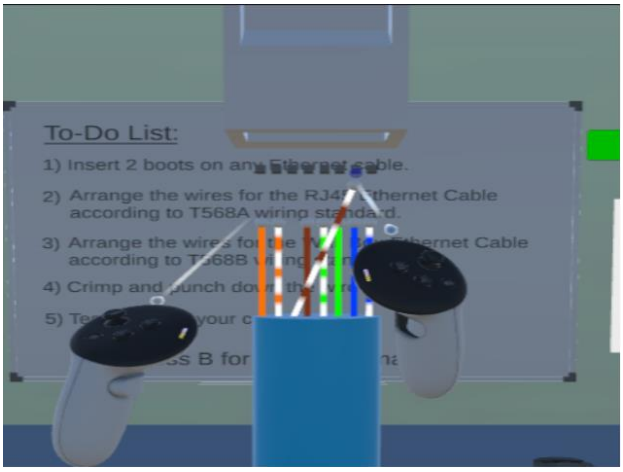


Fig. 2. RJ45 Termination using controllers

Once the participant had completed the RJ45 side, they could move to the wall box. For the wall box termination, the participant had to do the same as for the RJ45 connector, but using a conventional wall box layout (Fig. 3)

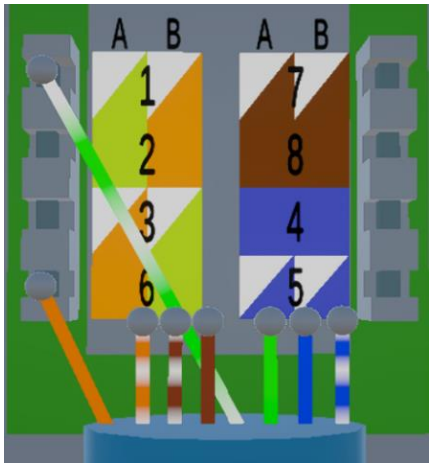


Fig. 3. Wall box termination using controllers

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After the wall box was terminated, the user could go back to the room at large and apply a network tester to determine whether the cables are connected correctly. The tester also provided some basic feedback to the user so they know what they need to work on, but in-depth feedback was not part of the initial testing.

4 Results and Discussion

All results displayed are from the aforementioned version of the application, before any changes were made, as will be discussed later in this paper.

4.1 Performance Metrics

Time was taken for the entire session; the highest value was taken as the worst %, and the lowest as the best %, with other values calculated as a percentage compared to the best and worst times.

For task success, the total number of tasks and sub-tasks was considered, and the amount completed successfully was indicated as a percentage of the total tasks.

Error rates were not calculated as the number of tasks not completed, but rather the total amount of errors per participant (Unique and repeated errors), with 0 being the best possible outcome and the highest value used to determine the worst percentage.

P1, who had prior real-world experience with cable termination, took the most time to ensure precision, resulting in the highest task success. In contrast, P2 struggled with both the controls and the technical requirements of the task, finishing with only a 29% success rate. This disparity underscores the knowledge gap the application aims to fill; those unfamiliar with the physical process found the virtual instructions insufficient. P3 took the least amount of time and made 4 errors relating to forgetting to add the boot and misaligning 3 of the cables. All participants requested assistance with the controls, even though a guide was available on the wall in the VE and a tutorial was available. The values per participant, along with the percentage values, are indicated in Table 1.

Table 1. Performance Metrics per participant

P#	Time Per Session(sec)	Time Per Session (%)	Task success (of 17)	Task success (%)	# of Errors	Error Rate (%)
1	930	0	16	94	1	9.09
2	805	76	5	29	11	100
3	765	100	13	76	4	36.36

4.2 Expectation Measure

Rather than per task level, the participants were asked to rate how difficult they thought it would be to complete all the tasks. P1 indicated 5 on the seven-point Likert scale, which is indicated as relatively easy, and, in the end, they found it to be a bit easier than expected (6). This aligns with the performance metrics. P2 indicated that they thought

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it would be difficult (2) and, in the end, found it to be difficult (2). This aligns with the performance metrics of P2 and indicates that there might be serious issues that need to be addressed. P3 indicated they initially thought it would be difficult (2), but in the end found it easy (6).

4.3 System Usability Scale (SUS)

The ratings for SUS were collected and averaged. The average SUS score of 70 indicated that the application is marginally usable; however, when considering the amount of task failures, it does support the fact that improvements are needed to create a more usable application in the future. Per participant, the score was relatively in line for P2 (62.5) and P3 (65), while P1 had a much higher score of 82.5. User 1 gave a more favourable score, likely due to their prior experience with the termination of Ethernet cables and found that their experience with the system was acceptable. Users 2 and 3 were less familiar with the termination process and found the information provided in the system unsatisfactory.

4.4 Net Promoter Score (NPS)

The NPS was collected using an 11-point Likert scale and calculated by subtracting the percentage of promoters (9-10) from the percentage of detractors (0-6). While the NPS was at 100%, this is not a true reflection of the usability, but rather a reflection of the need for such a system.

4.5 Single Usability Metric (SUM)

The SUM was calculated from all the performance metrics as well as the SUS scores. enables practitioners to combine all sub-metrics from various tasks into one comprehensive score that represents the overall usability of a product or experience. This single score provides a quick snapshot of how usable the product is. Generally, a SUM score below 50% indicates poor usability, while a score of 50% or higher suggests good usability, though more detailed interpretation may vary depending on context[19, 20]. The NPS was left out due to the inaccurate reflection of the true usability of the system, and the expectation measure was left out in the SUM calculation due to it being a separate metric usually interpreted in a graph form. In the calculation time per session, task success, SUS and error rate all had equal weights (Table 2).

Table 2. SUM Percentages and Averages per participant

P#	Time Per Session (%)	Task success (%)	Error Rate (%)	Average SUM
1	0	94	9.09	62.03
2	76	29	100	64
3	100	76	36.36	59.12

The SUM score of the VR system is 61.72%. This indicates a valid level of usability but does not underscore the issues participants experienced. However, when looking at

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issues, it was mostly related to a lack of knowledge in the termination of network cables, with some minor issues with other aspects. While difficult to say with only 3 participants, it does open a new area, which, once again, emphasises the gap between learning something in theory and then having to apply it in practice. This will need to be investigated in future research.

4.6 Qualitative Data

Each user had the option to comment and suggest improvements, while the facilitator (MK) also observed and collected data while the participants were busy with the usability tests. The Qualitative data is presented per participant.

P1 suggested adding an option to redo the wiring for the RJ45 and Wall Box cables before they are crimped, as this would better reflect how the termination process works in real life. The developer (MK) implemented this feature in both Practice Mode and Assessment Mode.

In addition, the Restart button was removed from the control panel in Practice Mode, since this button previously reloaded the entire scene, allowing users to start from scratch.

P2 suggested adding labels to each cable to make it easier to identify which cable they were working on. During their session, they were unsure about which cable they were working on and unsure of which order the cables had to be in, which negatively affected their experience compared to the other two users. To address this, the developer (MK) added labels above both Ethernet cables and included dedicated steps for each cable on the whiteboard, specifying the specific wiring order for that cable (e.g., RJ45 Cable arranged in T568B, and Wall Box Cable arranged in T568A).

P3 suggested adding instructional videos to the Tutorial UI to visually demonstrate the information presented, making it easier to understand. In response, the developer (MK) incorporated short video clips into selected sections of the Tutorial UI where visual explanations would be most beneficial. The wording was also refined throughout the Tutorial UI to make the instructions clearer and more user-friendly.

5 Application Improvements

Qualitative feedback directly informed several immediate updates to the application. P1 noted that in real life, wiring can be adjusted before the final crimp; consequently, we added a redo button (Fig. 4) for the wiring phase. To address P2's confusion, labels were added above each Ethernet cable to clearly identify which end was being worked on.

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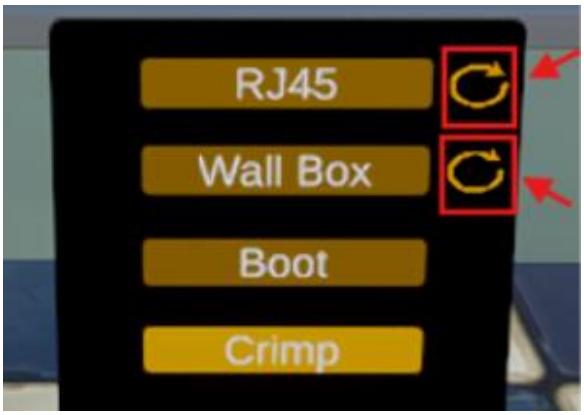


Fig. 4. Addition of Redo Buttons

The tutorial section was complemented by adding short videos that showed how the users could interact with the various objects in the simulation, as can be seen in the example of Fig. 5. This includes all the possible actions like cable crimping, wall-box punch down and the testing of the completed cable.

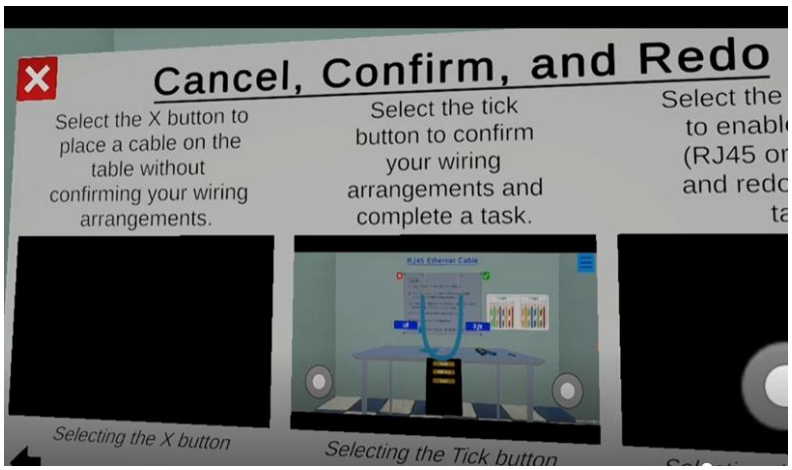


Fig. 5. Improved tutorial section

In assessment mode (which was not tested), all aiding material was removed since this will be used after the student has felt that they have practised enough, then they can test their skills in assessment mode. This mode also has a timer to limit the amount of time they must complete the termination of the cables (Fig. 6).

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Fig. 6. Assessment mode VE and overview

While not a suggestion from the participants, the developer also incorporated in-depth feedback for the assessment mode that can be tested in future iterations and will assist in providing students with valuable feedback on where they went wrong and what they must change (Fig. 7)

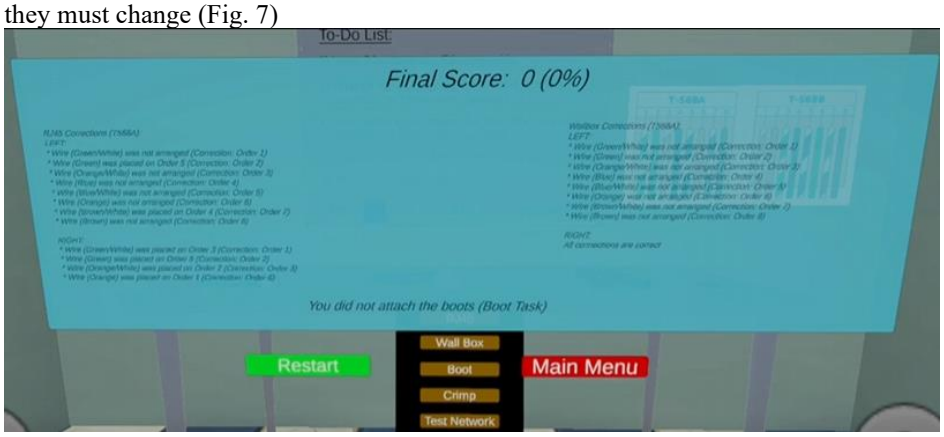


Fig. 7. Improved Assessment mode feedback screen

6 Ethics

Ethical approval for this study was obtained under the ethical clearance number UFS-HSD2025/0440. All participation was voluntary, and participants could withdraw from the process at any time without negatively affecting relationships with the researchers.

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7 Limitations and Future Work

While this pilot study provides a foundational understanding of using VR for technical hardware training, several limitations must be acknowledged. The most prominent constraint was the sample size; with only three viable participants, the quantitative data, including the SUS and SUM scores, serve as an initial indicator rather than a statistically significant representation of the entire student body. Furthermore, the exclusion of a participant due to severe cybersickness highlights a known limitation of immersive VR, which is the physiological barrier that can prevent some students from accessing the technology entirely. Additionally, the study focused exclusively on the Practice Mode within the VE, which does not account for the learning curves associated with the mobile version or the high-pressure Assessment Mode, where instructional scaffolding is removed.

Building on these findings, future research will adopt a more longitudinal approach. For the future, the plan is to conduct a comparative study involving a larger cohort of undergraduate students using a larger number of tools that can be combined to determine the usability and UX, which can in turn be used to improve the application, including to measure knowledge retention over time, specifically comparing those trained in VR against those using traditional physical labs. Technically, the next phase of development will focus on refining the physics of the crimping tool and enhancing the haptic feedback to mimic the tactile click of a successful termination. Furthermore, the intent is also to integrate a multi-user Collaborative Mode, allowing a lecturer to enter the virtual space alongside a student to provide real-time, remote guidance. Finally, validating the mobile iteration will be a priority to ensure that students without access to expensive HMD hardware can still achieve the necessary competency in T568A/B standards.

Seeing that there is currently no comparison of how participants performed with the VR platform vs the real thing or for those that only received theoretical training, it limits the findings and applicability of the results and the VR application. This can, however, be looked at in future research. Furthermore, a measure to determine cybersickness was not incorporated and can be incorporated in future studies to determine the onset and possible solutions to address the issue of CS during the VR experience.

8 Conclusion

This research underscores the ongoing challenge of transitioning students from theoretical understanding to hands-on proficiency in network cabling. The pilot study of the VR termination application demonstrated that immersive technology could provide a viable, cost-effective platform for practising complex technical tasks that are often limited by physical space and resources. While the initial usability metrics indicate a valid level of effectiveness, the feedback from participants proved invaluable for identifying specific UX friction points.

By incorporating user-driven enhancements, such as instructional video clips and clearer labelling, the application has been refined to better support novice learners.

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Although the small sample size limits broad generalisations, the results provide a strong foundation for future cycles of research.

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Evaluating the Undergraduate Information Systems Curricula in South African Universities

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Abstract. The growing technology evolution globally necessitates the need for Information Systems (IS) curricula's regular review to meet industry skills demands, on a country-by-country basis. This study describes a review of 18 South African undergraduate IS programs from 14 universities using the IS2020 curriculum guidelines. Data was collected from secondary data sources, and content analysis was performed to map course offerings to IS2020 competencies. The findings reveal that most IS programs are Commerce programs, and common competencies offered include Application Development, IS Foundations and Systems Analysis & Design, while the least common competencies offered are Emerging Technologies, Digital Innovation and Mobile Development. The findings imply that IS educators need to increase the offering of courses related to innovation and emerging technologies, given the potential benefits of these skills to the South African economy. The findings of this study can inform the development of curriculum guidelines that are contextually relevant and more easily adaptable across diverse African settings.

Keywords: IS2020, IS Curricula, Higher Education, Curriculum alignment, IS Education.

1 Introduction

The adoption of Information and Communication Technologies (ICTs) has been linked to several positive societal developments, including economic growth, longer life expectancies, and improved access to education [1]. Several factors affect countries' ability to harness the benefits of ICTs. These include ICT infrastructure, national governance, financial development, research and development investments, and human capital [2]. The human capital factor is the focus of our study.

When it comes to human capital and ICTs, a recurring theme is that of the ICT skills shortage. The ICT skills shortage has both quantitative and qualitative components. From a quantitative aspect, it is widely accepted that globally, the demand for ICT skills is greater than the supply [3]. From a qualitative aspect, the relevance of ICT education is constantly being questioned. Several studies have been conducted, which highlight

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the mismatch between ICT education and the needs of ICT education stakeholders, particularly industry, indicating that this is a topic of concern [4, 5]. Addressing the shortcomings in ICT education that lead to the qualitative aspect of the skills shortage requires a good understanding of what is taught in ICT programs, which is what this study attempts to provide [6].

ICT skills can be obtained through computing degree programs, such as Information Systems (IS) [7]. Unfortunately, there is a lack of literature on IS curricula in Africa compared to what is available for developed nations [8]. African countries face similar educational challenges, such as staff and resource shortages [9]. However, they also have different social, cultural, economic, legal and technological realities and therefore different educational demands [10, 11]. It is therefore important to conduct IS education research on a country-specific basis. In this study, we review IS curricula offered at South African universities. The aim is to contribute towards the literature on IS curricula in African countries and to respond to the call for country-specific studies on IS curricula. The study focuses only on IS programs at public universities in South Africa. Studies like these are beneficial because they help IS faculty understand what their peers are offering and also help stakeholders, such as employers, parents, and potential students, compare offerings across institutions [12].

Given these issues the study aims to answer the following research questions:

1. What are the different types of IS programs offered at South African universities?
2. In which academic units are these IS programs housed?
3. What courses are taught in these IS programs, and how do they align with model curricula guidelines?

2 Literature Review

IS curricula are implemented differently across countries [13]. As a result, many studies evaluating IS curricula focus on a single country. Bell et al. [14]) evaluated 127 undergraduate programs in the USA to determine their adherence to the Information Systems 2010 (IS2010) curriculum guidelines. In their study, Bell et al. [14] found that 97% of programs offered Data and Information Management. This was followed by Foundations of IS (87%), Systems Analysis and Design (84%), IT Infrastructure (70%), IS Project Management (38%), IS strategy, management, and acquisition (29%) and Enterprise Architecture (17%). The most popular course that could not be mapped to the seven core courses was Programming/Application Management, which was found in 81% of programs [15]. The other courses were Capstone Project (44%), Web Development (19%), Microcomputer Applications (18%), Electronic Commerce (14%), Operations Management (9%), IS Security (8%), Decision Support and Expert Systems (6%), Business Intelligence and Analytics (6%) and Global Information Systems (4%) [15].

Hwang et al. [16] used the IS2010 curriculum to identify the core IS courses taught in 394 IS undergraduate programs in the USA. The findings showed that data and Information Management was the most widely offered course, with 87.3% coverage [17].

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This was followed by Systems Analysis and Design, which was offered in 79.7% of programs and IS Project Management, which was offered in 66.2% of programs. The order of coverage for the remaining courses was Foundations of IS (62.7%), IT infrastructure (32.2%), IS strategy, Management, and Acquisition (15.5%) and Enterprise Architecture (13.5%). Several courses were found which could not be categorized as core courses according to IS2010. These include Programming (72.6%), web development (26.1%), Application development (35.8%), Business intelligence (13.5%), Mobile and E-commerce (10.9%), Capstone Project (9.9%) and Cybersecurity (7.9%) [17].

Hol et al. [16] conducted a case study of 227 computing programs across forty institutions in Australia. The authors categorized the programs into the various disciplines defined by the Computing Curricula 2020 (CC2020) guidelines and found that 28 of the computing programs in Australia offered IS as the primary major [19]. This represented 9% of computing programs in 2022 and decreased compared to the 34 programs that existed five years earlier. Hol et al. [16] also noted which academic units housed the IS programs specifically. The findings showed that the majority of IS programs were offered by STEM departments, with a smaller number offered by business schools [19].

Another area of interest to the authors was what dual majors (computing + X) programs were being offered in Australia. Of the 52 Computing + X programs Hol et al. [16] found, six were IS + X programs. Computing + X programs are becoming more common, particularly in IS, with programs such as Finance + IS and Accounting + IS gaining in popularity. This is an interesting aspect of the evolution of IS education and represents potential competition to traditional standalone IS degrees [20].

3 Theoretical Background

The IS discipline can be conceptualised as the study of social actors, technology and the phenomena that occur when they interact [21]. There are several different names that are used in academia to refer to the IS discipline. These include informatics, computing, information technology, and information management [13, 22]. Like other computing disciplines, IS has model curricula guidelines. Model curricula guidelines are curriculum guidelines developed by international professional and scientific bodies such as the Association for Information Systems (AIS), the Institute for Electrical and Electronics Engineers (IEEE) or the Association for Computing Machinery (ACM) [13]. Examples of such guidelines include IS' 90, IS '97, MSIS 2000, IS2002, MSIS 2006, IS2010. Undergraduate recommendations are prefixed with 'IS' while graduate guidelines are prefixed with MSIS. The most recent guidelines are IS2020.

IS2020 recommends competencies as opposed to courses. A competency can be spread out across multiple courses or combined in a single course with other competencies. This gives IS faculty the ability to tailor their curricula to their specific context [13]. IS2020 defines 19 competency areas, nine of which are elective and 10 of which are required. These competency areas are categorised into six competency realms depicted in Figure 1. The areas in bold are required, while those in italics are elective.

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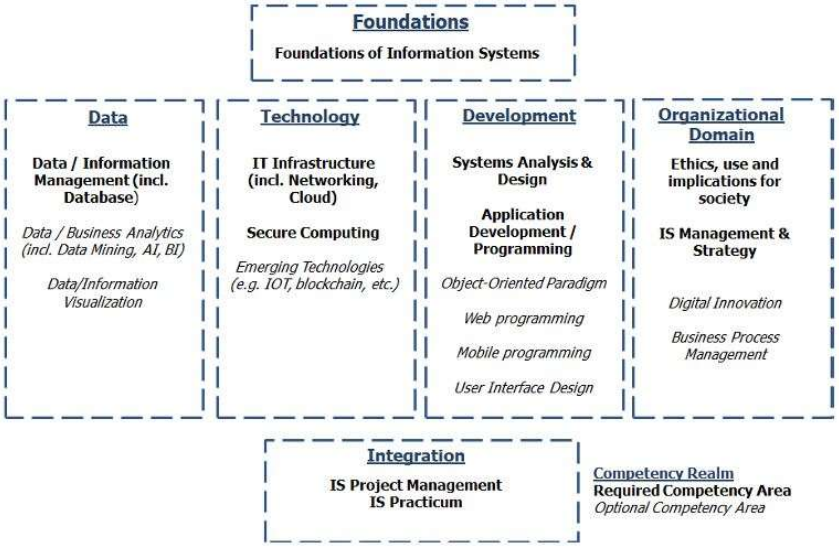


Fig. 1. Competency areas from IS2020 [13].

4 Methodology

Our study utilized the Secondary Data methodology. This is a methodology identified by Palvia et al. (2003) in their list of methodologies that are used in IS research. Secondary data uses information such as financial and accounting reports, archival data and publicly available statistics as a data source [23]. In the case of our study, we used publicly available university information.

4.1 Data Sample

The population of the study is undergraduate IS programs that are taught at South African public universities. We define an IS program as a degree which has "Information Systems" in the name. In South Africa, there are 26 public universities. Our focus is solely on IS; however, we do recognise that different names can be used to refer to IS. Therefore, programs called Informatics, Business Information Systems and Information Systems management were considered [13]. We also included programs that were Information Systems + X programs, such as Information Systems and Finance. In South Africa, undergraduate degrees are typically three years in duration. However, some programs are 4 years in duration, which were included in our study. There are also four-year extended degree programs, which are extended versions of the three-year programs designed to provide additional support to students. Since these four-year extended programs are very similar to the 3-year programs in content, we treated them as

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duplicates of the third-year programs and excluded them. Applying this criterion, we found 19 IS-related programs from 15 different universities. This means 11 of the 26 universities do not offer IS or IS + X programs. The authors found computing programs, such as Computer Science degrees that offer IS as a course, but these did not meet the criteria of an IS program. One of the 19 programs did not have any publicly available information that the authors could find and had to be removed. Therefore, the final data set consisted of 18 programs from 14 different universities.

4.2 Data Collection

The data was collected from March to April 2025. The data was collected from publicly available sources such as websites and faculty handbooks. We started with a list of public universities in South Africa sourced from the Department of Higher Education and Training website. We then searched the internet for IS programs from these institutions through a Google search using the following query:

"University of X" + "Information Systems"

Using the search results, we were able to create a list of IS programs available at these institutions. We then searched for curriculum descriptions of these programs. These were found on department and faculty websites or on documents such as Faculty handbooks, which were found on the websites [24] [25], [26, 27], [28, 29],[30],[31], [32, 33],[34],[35],[36, 37][38, 39][40], [41], [42–44]. Using Microsoft Excel, each IS program was recorded along with the courses taught in each year. Many programs require an elective course, and we included all these courses in our lists.

4.3 Data Analysis

Content analysis was used to analyse course data. Content analysis is a technique that can be used to analyse textual data [45, 46]. Content analysis categorises the data using codes that are either predefined or emerge from the data analysis [45].

Each course description was analysed to see which IS2020 competency it could be mapped to. In some cases, the mappings were straightforward, as there were courses with names such as "Systems Analysis" and "Web Systems" which could be directly mapped to a competency. Some courses are mapped to two different competencies. This was particularly the case with the programming courses, which teach both application development and object-oriented programming, for example. In such instances, the same course would be recorded against both competencies. Other courses, which did not map directly, required the authors to use their judgment using the competency descriptions as a guide. For example, E-commerce courses were included under the web development category even though E-commerce was not explicitly mentioned as forming part of this competency in IS2020. This decision was taken because the web development competency in IS2020 includes front and back-end web application development [13]. The authors also mapped some non-IS courses to the IS2020 competencies

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where the authors felt this was appropriate. An example of this was Statistics courses. These courses were mapped to the Data and Information Visualization competency. The reason for this was that IS2020 describes this competency as teaching statistical analysis. Conducting statistical analysis requires some understanding of statistics.

Courses that could not be mapped to IS2020 were also recorded and assigned to their categories. These included Accounting, Marketing, Human Resources, Mathematics and Finance.

The coding was conducted by the authors. One coder initially coded the data and then a second coder mapped the data again. Any conflicts were resolved through internal discussions which were guided by the IS2020 descriptions. When a course was mapped to a competency, the authors marked this on an Excel sheet. Once all the courses were mapped, the authors applied an Excel formula to calculate the totals per competency and present this in a pivoted table format. The authors also calculated a percentage total by dividing the number of programs that offer a competency by the total number of programs, as shown in Table 3. This approach is similar to that used by other studies which evaluated IS curricula [14, 15, 16].

The authors also captured the degree names and standardised them where possible to enable the values to be combined where possible and treated as the same degree. For example, BCom (Information Systems) and BCom in Information Systems were mapped to Bachelor of Commerce (Information Systems).

5 Findings Presentation

The study was conducted to answer the research questions outlined in the Introduction. The results have been organised according to these questions.

5.1 IS programs in South Africa

The programs that were analysed are displayed in Table 1. The table shows 12 variations in the program names. Bachelor of Commerce (Information Systems) accounted for six of the 18 programs. There were other degree names which reflected the different naming of IS programs, such as Bachelor of Commerce (Business Information Systems), Bachelor of Commerce (Management Information Systems), Bachelor of Commerce (Informatics - Information Systems) and Bachelor of Computer Information Systems. In terms of IS + X programs, we identified 5 such programs which combined IS with one of Computer Science (2), Finance (1), Mathematics (1), and Technology (1).

Table 1. IS degree programs and their respective faculties

Faculty	Degree Program	Count
Commerce	Bachelor of Business Science (Information Systems)	1
Commerce	Bachelor of Commerce (Information Systems Management)	1

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Commerce	Bachelor of Commerce (Information Systems and Technology)	1
Commerce	Bachelor of Commerce (Business Information Systems)	1
Commerce	Bachelor of Commerce (Informatics - Information Systems)	1
Commerce	Bachelor of Commerce (Information Systems and Computer Science)	2
Commerce	Bachelor of Commerce (Information Systems and Finance)	1
Commerce	Bachelor of Commerce (Information Systems)	6
Commerce	Bachelor of Commerce (Management Information Systems)	1
Faculty of Natural and Agricultural Sciences	Bachelor of Computer Information Systems	1
Engineering and The Built Environment	Bachelor of Information Technology (Information Systems)	1
Science, Engineering and Technology	Bachelor of Science (Mathematics and Information Systems)	1
	Total	18

5.2 Academic units of IS programs

Most programs, 15, are housed in Commerce faculties. Of the remaining three programs, two are in science faculties, and one is in an Engineering faculty.

5.3 IS courses and competencies in IS programs

Table 2 shows the percentage of programs in our study which offer a particular course recommended by IS2020. All the programs offered Application Development & Programming. Systems Analysis and Design and Foundations of IS both had 94% coverage. The one program that did not have a course that could be mapped to Foundations in IS was one of the BCom (Information Systems and Computer Science) programs. The program, however, did include introductory Computer Science courses. Data and Information Management had the next highest coverage at 89%.

At the lower end, Emerging technologies and Business Process Management had 33% coverage, Digital Innovation had 28% coverage, while Mobile development had the lowest, at 6%. The low coverage of mobile development was surprising, given how ubiquitous mobile technologies have become. Even in the early 2010s, researchers such as Babb and Abdullat (2012) argued that mobile technologies were no longer a fad and needed to be incorporated into IS curricula [48]. The low coverage of Digital Innovation is another concern. Digital innovation has a body of research dating back to the 1990s [49]. Research also shows a gap between market opportunities and the organisational

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capabilities needed to leverage them through digital innovation [49]. Given the rich body of research and the market's need for these skills, the authors argue Digital Innovation should be taught more widely. Emerging technologies include innovations such as blockchain and the internet of things, which can have a transformational impact in areas such as Finance and Healthcare [50]. Adopting emerging technologies is important for organisations, as research shows that successful early adopters gain a competitive advantage [51]. At a national level, embracing emerging technologies can be economically beneficial, which is why governments across the world, including South Africa, have established initiatives to harness them under the banner of the 4th Industrial Revolution (4IR) [51]. Central to harnessing these opportunities is a qualified talent pool, which is why IS programs need to include emerging technologies in their curricula. Secure computing is a competency that the authors argue warrants more coverage in SA. Cyberattacks are estimated to cost the South African economy 2.2 billion Rands annually [52]. There is a skills shortage in this area, and organisations are continually increasing their budgets to address the growing digital threat [52]. We argue these factors justify greater coverage of Secure Computing within IS programs.

Table 2. Coverage of IS2020 competencies in IS undergraduate degrees in SA

IS2020 Competency	Count	SA %
Application Development & Programming	18	100
Systems analysis & design	17	94
Foundations of IS	17	94
Data / Info. Management	16	89
IS Project Management	15	83
Data / Info Visualization	14	78
IS Practicum	14	78
Data/Business Analytics (incl. Data Mining, AI, BI)	13	72
Object-oriented paradigm	13	72
User interface design	13	72
IT Infrastructure	12	67
Secure computing	12	67
Web development	12	67
Ethics, use and implications for society	12	67
IS management and strategy	10	56
Emerging technologies (e.g., IOT, blockchain)	6	33
Business Process Management	6	33
Digital Innovation	5	28
Mobile development	1	6

5.4 Non-IS courses

To gain a holistic understanding of the degrees, we also analysed the non-IS courses and the results are shown in Table 3. The courses in this category with the most coverage were mostly Commerce courses, which makes sense given that most of the degrees

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we analysed were Commerce degrees. Accounting, Economics, and Business Management all have coverage of 78%. Mathematics has 61% coverage, Marketing has 56%, and Finance has 50%. Academic Research (11%), Psychology (11%), Languages (11%), and Community Service (6%) had the lowest coverage.

Table 3. Non-IS courses in IS undergraduate degrees in SA

Non-IS	Count	Percentage
Accounting	14	78%
Economics	14	78%
Marketing	10	56%
Mathematics	11	61%
Business Management	14	78%
Entrepreneurship	5	28%
Professional Skills	6	33%
Philosophy	2	11%
Finance	9	50%
Human Resources	3	17%
Evidence-based Management	4	22%
Academic Literacy	3	17%
Community Service	1	6%
Academic Research	2	11%
Psychology	2	11%
Languages	2	11%

6 Findings Discussion

This section discusses the findings in relation to our research questions. To enrich the discussion, the authors draw on similar studies conducted in other countries. At the time of authoring this paper, the authors were unable to find papers that investigated IS2020 to compare with, and so the authors relied on studies that used the IS2010 guidelines. Using both IS2010 and IS2020 to assess IS education has been used in other studies. For example, Steen and Pierce (2023) investigated whether IS2010 and IS2020 guidelines matched the requirements of the Swedish job market based on ICT-related job adverts. Although the IS2010 guidelines are different to the IS2020 guidelines, there are several similarities between IS2010 and IS2020 that allow for some comparisons. For example, IS2010 has seven core courses, six of which can be mapped to IS2020 competency areas as shown in Table 4 [13].

Table 4. Similarities and differences between IS2010 and IS2020 core areas [13].

IS2010 core courses	IS2020 required competency areas
Foundations of Information Systems	Foundations of Information Systems
Data and Information Management	Data/Info. Management
IT Infrastructure	IT Infrastructure

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IS Project Management	IS Project Management
Systems Analysis and Design	Systems Analysis and Design
IS Strategy, Management, and Acquisition	IS Management & Strategy
Enterprise Architecture	(not included as a competency area)

There are also similarities in the elective IS2010 courses with the IS2020 competency areas as depicted in Table 5. Application Development, Business Process Management, Data Mining and Business Intelligence, Human Computer Interaction, IT Security and Risk Management, IT audit and controls and IS Innovation and New Technologies are IS2010 courses that can be mapped to IS2020 competencies.

Table 5. Mapping of IS2010 electives to IS2020 competencies

IS2010	**IS2020**
Application Development	Application Development & Programming
Business Process Management	Business Process Management
Data Mining and Business Intelligence	Data / Business Analytics (incl. Data Mining, AI, BI)
Human Computer Interaction	User interface design
IT Security and Risk Management	Secure computing
IT audit and controls	Secure computing
IS Innovation and New Technologies	Emerging technologies (e.g., IOT, blockchain)

6.1 What are the different types of IS programs offered at South African universities?

Of the 18 programs we analysed, 13 are solely IS majors based on their names. The degree names do vary and include Information Systems, Computer Information Systems, Informatics, Business Information Systems, and Management Information Systems. There are five dual major programs that couple IS with another discipline. These disciplines are Finance, Technology, Computer Science, and Mathematics.

6.2 In which academic units are these IS programs housed?

The majority of IS courses, 15 out of 18, are in Commerce faculties. As a result, South African IS programs tend to include business subjects such as Accounting, Finance, Marketing, and Business Management. Steen and Pierce (2019) conducted a review of IS curricula in Sweden. Based on their search criteria, they identified 19 IS programs offered by 17 different institutions. These 19 programs were housed in four different types of faculties: Social Science (3), Social Science and Technology (6), Technology (4), and Business (4) [54]. This shows that the majority of IS programs in Sweden are in Social Science faculties, which supports the position of Hol et al. [16] who argue that IS in Scandinavian countries has a socio-technical flavour. The academic placement of IS in South Africa is similar to the U.S., where IS programs are typically found in

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Business schools, which are also commerce-oriented [13]. Richardson, Burstein, Hol, Clarke, and McGovern (2018) is an Australian study that evaluated IS curricula against IS2010. Their study analysed 33 programs from 30 universities. In terms of academic placement, they found four categories of faculties which offered IS qualifications: Business (14), Science and Engineering (14), Science, Engineering and Technology (4), and Information Technology (1). This shows that Australia has a more even distribution between Commerce and Science, Engineering and Technology faculties, as compared to South Africa [55].

6.3 What courses are taught in these IS programs, and how do they align with model curricula guidelines?

The findings indicate that the courses that are most common (i.e., have two-thirds or more coverage) are generally courses that cover IS foundations, data subjects (e.g., databases, SQL development, Business Intelligence), development (e.g., programming, application, and web development), and integration (e.g., project management and capstone projects). The organizational and technology competencies have some competencies that meet the two-thirds threshold. These are Systems Analysis and Design, Ethics, Secure Computing, and IT Infrastructure. In terms of non-IS courses, most programs offer Commerce courses such as Economics, Accounting, and Business Management. In our view, this is expected, given that the majority of IS degrees are in Commerce.

Table 6 shows how the coverage of IS2020 competencies in South Africa (SA) programs compares to the coverage of IS2010 courses in other studies from Sweden (SW);[54], Australia (AU); [55] and USA [47]. To simplify the comparison, we compared courses to competencies only when there was a 1-to-1 mapping, e.g., Foundations of IS and Systems Analysis and Design. Comparisons of competencies, such as Secure Computing, which map to more than one course, were excluded. We took this decision to avoid double-counting an institution when we simply add two different course totals, which could result in totals exceeding 100%.

Table 6 shows that Application Development & Programming has 100% coverage in both SA and Sweden, indicating that IS in both countries emphasizes programming skills. The USA study has slightly lower coverage of 84%. We were unable to map the Australian study scores for this category as the authors treated Application Development and Programming as separate subjects [47, 54, 55].

The competencies where the differences between all 4 studies are small (<10%) are Systems Analysis and Design and Data and Information Management. These competencies have coverage of 89% to 97% across all four studies, suggesting that most IS programs in SA, Sweden, the USA, and Australia align on the importance of these competency areas. For the Foundations in IS competency, SA (94%) has slight differences in coverage with the USA (84%) and Sweden (100%), and a significant difference (>10%) with Australia (76%) [47, 54, 55].

SA IS programs have the highest coverage of IS Project Management at 83%, while the USA has the lowest at 28%. South African programs also have the highest coverage of IS Management and Strategy (56%) and Emerging Technologies (33%). Business Process Management has low coverage across all four studies, with the highest

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coverage being 42% in Sweden. SA has the second-highest Business Process Management coverage at 33%. SA and Sweden share similar levels of coverage in User Interface Design of 72% and 79%, respectively. However, there are large differences between SA and the USA and Australia, with the USA study revealing that no programs cover this competency area [47, 54, 55]. SA coverage of IT infrastructure (67%) is high compared to Sweden (26%) and Australia (45%) and is equal to the USA (68%) [47, 54, 55].

Table 6. Comparison of IS2020 competencies in IS from SA, Sweden, Australia, and the USA.

IS2020 Competency	SA%	SE%	AU%	USA%
Application Development & Programming	100	100		84
Foundations of IS	94	100	76	84
Systems Analysis & Design	94	90	97	90
Data / Info. Management	89	95	94	94
IS Project Management	83	68	70	28
Data / Business Analytics	72		15	
User Interface Design	72	79	27	0
IT Infrastructure	67	26	45	68
IS Management and Strategy	56	32	30	30
Emerging Technologies	33	16		5
Business Process Management	33	42	21	6

7 Conclusion

The aim of this study was to provide an understanding of IS undergraduate programs in SA. The authors found that most IS programs in South Africa are Commerce degrees and thus include subjects such as Marketing, Finance, Human Resources, and Business Management. The most common competencies offered include Application Development & Programming, IS Foundations, Systems Analysis & Design, and Data & Information Management. The coverage of these competencies in South Africa is similar to USA, Sweden, and Australia, suggesting that IS programs in SA do align to some extent with those globally. The study identified low coverage in SA programs across mobile technologies, secure computing, digital innovation, and emerging technologies. The low coverage found could be impacted by the data sources used in this study which were predominantly course descriptions and publicly available information. If these sources did not explicitly mention these topics, then the coverage of the topics would be recorded as lower than they are. Nevertheless, the authors recommend offering more courses to develop these competencies, given the demand for these skills and the potential socio-economic benefits. For example, emerging technologies have an important role in making the manufacturing industry in SA more competitive. This is important because SA has a high unemployment rate, which can be alleviated to some extent by manufacturing jobs, given the industry's size [51].

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This study is intended as a first step towards a concerted effort to document IS programs in SA. This effort benefits IS stakeholders in SA (educators, industry, students) by helping them understand the offerings in SA and how they differ from offerings in other countries. Future research can explore how these differences are shaped by contextual realities to better understand, for example, why Emerging Technologies are not being taught more widely or why IS Management and Strategy is more prevalent in SA than other countries. Understanding these issues can inform discussions regarding the changes that can be made to IS curricula to reduce the ICT skills gap.

Documenting IS programs also contributes to the literature on IS in Africa and can inform model curriculum guidelines. Currently, these guidelines rely on European and North American literature to inform decisions, such as what courses to drop [8]. This makes it harder for IS educators in Africa to adopt these guidelines, or worse, implement IS programs that are not suitable to the African context [56]. This, in turn, exacerbates the IS skills shortage in Africa.

The main limitation of this study is its reliance on the quality of the secondary data used. We relied heavily on course descriptions, and if they were not sufficiently specific, we would not be able to capture everything the course offers. For example, it is possible that courses covering web development also touch on mobile technologies, but do not explicitly mention it in their course descriptions. Another study can address this limitation by surveying IS educators in SA to determine how their programs align with IS2020. Another limitation is the lack of similar studies that used IS2020. The authors urge researchers to conduct similar IS2020-based studies in other countries.

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First-Year Computer Science and Informatics Students' Experiences of an Immersive Virtual Reality Application for Computer Hardware Assembly

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Abstract. Teaching computer hardware assembly to large groups of students is becoming increasingly difficult due to the high cost of components and the physical damage caused by repeated use. This study explores the use of a locally developed, cost-effective immersive Virtual Reality (VR) application as a practical solution for first-year computer science and Informatics students at a South African university. By using VR, the authors aimed to bridge the gap between theoretical learning and hands-on practice, providing a safe environment where students can experiment without the risk of breaking expensive equipment. Using a mixed-methods approach, the research evaluated the usability and user experience of 97 participants who assembled a virtual desktop using Meta Quest headsets. The quantitative results indicated high levels of system usability (SUS = 72.89) and a strong Net Promoter Score of 74.23. Additional metrics confirmed the application's effectiveness, with an Ease of Use rating of 89.78%, an After-Scenario Questionnaire (ASQ) score of 91.12%, and an overall satisfaction score of 91.57%. The Virtual Reality Sickness Questionnaire (VRSQ) score remained low at 16.51, suggesting minimal cybersickness. Most users had a 100% completion rate. However, qualitative feedback identified critical errors, such as components falling through the virtual floor and difficulties with cable management. While the novelty effect of VR likely influenced the high satisfaction ratings, the findings prove that locally developed VR interventions are a viable, scalable alternative to traditional labs. While technical refinements are needed, immersive VR offers a powerful tool for mastering hardware assembly in resource-constrained educational settings.

Keywords: Computer Hardware, Computer Education, Virtual Reality, Human-Computer Interaction

1 Introduction

Building a computer and identifying its components are basic requirements for computer science and informatics students. Teaching them to assemble a desktop computer using various components has become increasingly difficult due to the high cost of

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purchasing new hardware, and this hardware subsequently often being damaged after repeated use. This makes it unfeasible to allow 200 or more students to build and rebuild computers using new and expensive equipment [1]. Advancements in the field of extended reality (XR), which can allow students to practice assembling computers in a safe environment repeatedly without the need for expensive computer hardware that needs to be purchased or replaced regularly, have emerged [2].

XR is an umbrella term used to describe technologies that allow the user to experience digital worlds or digital components in different ways. As part of XR, there are currently three main sub-terms, namely virtual reality (VR), augmented reality (AR) and mixed reality (MR). VR has three subcomponents. The first two types are mobile or desktop-based VR, which refers to using either a mobile device, a desktop computer, or a laptop to interact with a virtual environment (VE). The third type is immersive or standalone VR, which refers to the use of a head-mounted display (HMD) such as the Meta Quest 3, this is a device the user puts on their head, that the user can use to be immersed in the VE and engage using either their hands or the touch controllers [3–5], which will also be the focus of this paper.

2 Background and Rationale

Research indicates that VR in education boosts student motivation, improves attitudes toward learning, and enhances knowledge retention [6, 7]. In computer hardware education, VR provides hands-on experience essential for mastering complex components. A VR-based assembly course developed at the University of Burgos demonstrated significant advantages over traditional and desktop-based methods [8]

- **Satisfaction & Usability:** Students found the VR application more engaging and significantly easier to navigate than desktop alternatives.
- **Understanding & Recognition:** The immersive environment improved visual recognition and the ability to apply knowledge to real-world scenarios.
- **Performance:** VR led to faster completion rates with fewer errors compared to 2D desktop versions.

These findings suggest that, as VR integration expands, it will become pivotal for fostering deeper understanding and improving learning outcomes in technical fields.

Another study, conducted by Agbo [6], indicated that students performing virtual simulations demonstrated more exploration initiative, which increased their learning experience since they were not afraid of breaking actual equipment while building something in VR. This study used 45 participants who engaged in a VR simulation attempting to enhance computational thinking. The findings indicated that their in-house solution was just as cost-effective as commercially available software [9].

While VR has been successful in multiple fields [3, 6, 7, 9, 10], purchasing already available solutions proved to be expensive, requiring licensing agreements that increase costs and, therefore, not being feasible given the current financial constraints faced by universities in South Africa. Coupling the high licensing costs with the fact that the purchase prices of hardware are even more expensive (as mentioned), a gap was

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identified to provide students with opportunities to learn about computer components and assembly using something other than images, textbooks and theory, which are not ideal.

To address this gap, an immersive VR application was created that could be used free of charge by first-year hardware students (at the institution where the authors are affiliated) to learn the basics of computer components and their assembly in a desktop computer. This application's usability and user experience (UX) were, however, not yet explored to determine if the students enjoyed the learning experience, and whether the VR application was usable in a first-year hardware module as a method of learning to build a desktop computer. Furthermore, there was a lack of research on how locally developed, cost-effective solutions performed in the specific contexts of South African higher education.

The research question derived from the problem is, therefore: How usable is the first iteration of the VR hardware application? The objective is to explore the usability and UX of the first iteration of the VR hardware application when used as part of a first-year computer science and informatics hardware module at a South African higher education institution, to investigate the viability of being incorporated in the curriculum as a possible cost-effective solution in future.

3 Methods and Materials

3.1 Methodology and Sampling

To complement the research, a complex mixed-method methodology [11] was deemed appropriate. This methodology entails a mixture of qualitative and quantitative results and allows qualitative data to be interpreted quantitatively and vice versa. For this research, some qualitative data was quantitatively measured in terms of the number of comments, and the qualitative data was also thematically categorised into the different themes obtained. Qualitative methods (retrospective think-aloud and comments) and quantitative methods (SUS [12], Ease of Use [13], ASQ [14] NPS [15], Satisfaction and VRSQ [16]) were used to measure the usability and UX of the VR application.

To complement the study the Technology Acceptance Model (TAM) was seen as the theoretical framework through which the study is conducted, since it falls well in line with usefulness, ease of use and attitudes towards the system [17].

A total of 263 first-year computer science and informatics students enrolled in a hardware module were conveniently [18] selected and asked to participate in the research. From the 263, a total of 99 students volunteered to complete the questionnaires (quantitative) and comment and be observed using the application (qualitative) (a response rate of 37,6%). Out of the 99 that completed the questionnaires, comments and observations, 97 data sets could be used for analyses; the other two were excluded due to missing data.

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3.2 Setup and Hardware

Various usability session slots were pre-scheduled, and to allow flexibility, students could select and book their sessions. During these sessions, participants had to build a desktop computer using an immersive VR application and an HMD. A total of five participants were taken per 15-minute session. If their 15 minutes concluded, they were stopped due to the time constraints of the venue bookings. Before the next participant used the HMD, one of the staff members would clean the headset using 70% alcohol wipes. Participants were immersed using either a Meta Quest Pro or a Meta Quest 3, which were the HMDs that could run the VR application and were available to the research team. Fig. 1 shows the layout of the venue and one of the sessions where participants were engaged using the HMDs.



Fig. 1. Venue and session setup (Image used with written consent from the participants)

The VR application consisted of a room where the participants received the tasks they needed to perform (see Fig. 2). These tasks were:

- Task 1: Mount the motherboard to the case wall.
- Task 2: Mount the central processing unit (CPU) and storage to the motherboard.
- Task 3: Install the CPU cooler.
- Task 4: Mount the random access memory (RAM) and the graphics processing unit (GPU) to the Motherboard.
- Task 5: Install the power supply (PSU).
- Task 6: Connect the component cables.
- Task 7: Attach the side panels.

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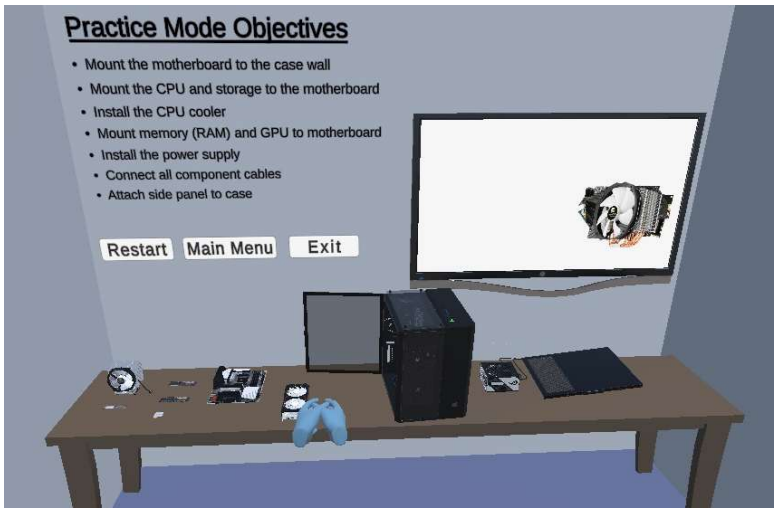


Fig. 2. Virtual Environment Layout

3.3 Data Collection and Analysis

The tools chosen to evaluate the application (previously mentioned), were well-known usability and UX tools, except for the added Virtual Reality Sickness Questionnaire (VRSQ) [16]. These tools were used to firstly determine task level experiences, ratings, and metrics (Ease of Use [13], Task Success, ASQ [14] and comments) and secondly, to determine the overall system usability and UX (SUS [12], satisfaction ratings and NPS[15]). The VRSQ was added to determine the level of cybersickness (CS) that participants experienced, since it is a common problem, often manifested from the use of immersive VR [16]. For qualitative data, participants were asked to answer three questions, which were:

1. What frustrated you the most while using the application?
2. What did you enjoy the most while using the application?
3. What would you suggest to improve the application?

The qualitative data were thematically analysed [19] and divided into the categories for usability issues (negative), usability findings (Positive) and Improvements.

4 Results and Discussion

4.1 Post Task Ratings: Ease of Use and Task Success

The post-task ratings for Ease of Use and metrics for Task Success are portrayed in Table 1. These were collected for each task once the task was completed, whether

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successful or unsuccessful. Values in Table 1 are specified as averages, with the standard deviation (STDEV) in brackets for Ease of Use, while Task Success is presented in percentage of tasks completed. For Ease of Use, a 7-point Likert scale was used, with higher values indicating better results.

Table 1. Post-task ratings Ease of Use, Average (STDEV), and Task Success % (n=97)

Task	Ease of Use	Task Success
Task 1 (Motherboard)	6.35 (1.23)	97.94%
Task 2 (CPU)	6.39 (1.05)	98.97%
Task 3 (CPU Cooler)	6.34 (1.19)	100%
Task 4 (RAM & GPU)	6.27 (1.20)	100%
Task 5 (PSU)	6.42 (1.04)	100%
Task 6 (Cables)	5.69 (1.57)	95.88%
Task 7 (Side Panels)	6.53 (1.12)	100%

The data in Table 1 indicates that all tasks were easy to perform, with all except task six having a rating of above 6. There were task failures in tasks 1, 2 and 6, the reasons being participants' inability to grab the motherboard, dropping the motherboard and CPU and not being able to pick it up again. In one situation, the motherboard fell through the floor, and the simulation was not complete since the motherboard was now missing. While not experienced by a lot of participants, these were major issues that had to be addressed in future iterations of the application.

4.2 Post Task Ratings: ASQ

The post-task ratings for ASQ results are portrayed in Table 2. These were also collected for each task once completed, whether successful or unsuccessful. Values in Table 2 are specified as averages with the standard deviation (STDEV) in brackets for each ASQ question. The ASQ measured 3 aspects of each task, namely effectiveness, efficiency and satisfaction. Participants rated their agreement on a 7-point Likert scale, with a higher score indicating a better level of each aspect.

Table 2. Post-task ASQ ratings and metrics indicated as average (STDEV) (n=97)

Task	Effectiveness	Efficiency	Satisfaction
Task 1 (Motherboard)	6.41 (1.09)	6.36 (1.1)	6.44 (1.02)
Task 2 (CPU)	6.39 (1.05)	6.46 (0.91)	6.40 (1.05)
Task 3 (CPU Cooler)	6.34 (1.19)	6.40 (1.1)	6.35 (1.17)
Task 4 (RAM & GPU)	6.33 (1.06)	6.32 (1.14)	6.39 (1.05)
Task 5 (PSU)	6.42 (1.08)	6.41 (1.11)	6.46 (1.04)
Task 6 (Cables)	6.13 (1.31)	6.12 (1.39)	6.34 (1.2)
Task 7 (Side Panels)	6.46 (1.03)	6.52 (0.99)	6.49 (0.98)

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Table 2 complemented the Ease of Use in the sense that all ratings were above 6, indicating very high effectiveness, efficiency and satisfaction levels. It is, however, of note that the STDEV was a little higher for task 6, which could be attributed to the larger number of task failures due to issues with grabbing the cables and, in some other cases, participants not knowing where the cables needed to be attached to the mother-board.

4.3 Post Session Ratings: SUS

The post-session ratings for SUS were collected and averaged (n=97). The average SUS score of 72.89 indicated that the application was, in fact, very usable; however, when considering the issues during tasks and the fact that the STDEV was 18.01, it does support the fact that improvements are needed to decrease the STDEV and to create an even more usable application in the future.

4.4 Post Session Ratings: NPS

The NPS was collected using an 11-point Likert scale and calculated by subtracting the percentage of promoters (9-10) from the percentage of detractors (0-6). The NPS indicated that the application showed promise for promotion and future use with an NPS score of 74.23.

4.5 Post Session Ratings: Satisfaction

Satisfaction with the entire application was determined using three questions to which the participants had to rate their agreement on a 7-point Likert scale. Table 3 depicts the averages for each question along with their respective STDEV.

Table 3. Post-session ratings for satisfaction (STDEV) (n=97)

Question	Average (STDEV)
I found the application visually appealing	6.13 (1.27)
I enjoyed using the application	6.67 (0.76)
The application was fast and responsive.	6.43 (1.05)

The results from the satisfaction ratings indicated high levels of satisfaction with all averages above 6, with a relatively close STDEV.

4.6 Post Session ratings: VRSQ

The VRSQ was used as a tool to determine the level of CS that participants experienced. With this scale, a lower score is better since it means a lower level of CS. The average CS score was 16.51, which is relatively low and indicates that the application in general should not induce CS. However, the STDEV of 22.07 led to the realisation that some participants did experience higher levels of CS. One possible reason could be that a

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subset of participants fell through the floor of the VE. Other possible reasons include rapid movements or frame rate issues, as well as lag in the tracking of the controller.

Regardless, the issues experienced, even though not by a lot of participants, were critical and needed to be addressed in future iterations of the application.

4.7 Qualitative Data

Set out in the following tables are the categorised qualitative data, which were thematically analysed. Each table depicts a different category, starting with the issues in Table 4 (negative), followed by findings in Table 5 (positive) and the improvements in Table 6. Along with the data is the number of participants who commented on it.

Table 4. Usability Issues

Usability Issues	Number Participants
Moving around in the VE	9
Connecting the cable or knowing where to connect the cables	9
Blurry graphics	4
The screen would sometimes go blank when moving in a direction	3
Struggling to mount the separate components	3
Grabbing and releasing items in the correct spot	3
Components kept falling	3
Components or the avatar fell through the floor of the VE	2

From Table 4, it seems as though some participants (nine) had issues navigating the VE, indicating not being familiar with the joystick, or that the movement was too fast. In future iterations, this could be enhanced by providing a more in-depth tutorial on using the controllers and testing the movement speed to scale to a more acceptable level.

Nine participants had issues connecting the cables in the correct spots, while some quoted issues related to grabbing the cable and others the fact that they did not know where the cable needed to be connected on the motherboard.

The blurry graphics were not an issue of the VE itself but were attributed to an adjustment that was not made correctly to accommodate the students' field of vision and eye spacing. This could be addressed by assisting participants in understanding how to manually adjust the spacing themselves until they are satisfied with what they see.

Three participants reported the screen going blank; this issue could not be isolated since it happened during different phases of the tasks. This will need to be investigated to determine the cause.

Other issues related to the mounting of components, where participants did not know where to mount them, or tried to mount them in the incorrect spot. This was linked to the grabbing and releasing of the components, where it did not stay in the correct place if the participant did not place it in the correct spot. One issue that was also picked up is that some participants struggled to predict depth within the VE. They would try to mount the component while still far away from the actual table; however, when asked, they thought they were standing next to the table.

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There were several other usability issues that impacted the experience, for example, some participants could not pick up items once dropped, and in two cases, the avatar of the user (and in another case, a component) 'fell' through the floor. As mentioned, while not experienced by many of the participants, these issues are critical and need to be addressed.

Table 5. Usability Findings

Usability Issues	Number Participants
Responsiveness and Ease of Use	33
Realistic Experience	6
Great learning experience	5
Challenging	3
Navigating the VE	1

From Table 5, the usability findings in terms of responsiveness and Ease of Use were highly praised. This contradicts some usability issues of other participants who had some negative experiences, which indicates that, should the issues be resolved, a better UX could be created.

Six participants indicated that the experience was very realistic and that they appreciated how it closely matched the real world. However, while this was the aim, some aspects, like applying thermal paste, screws, and spacers, were not part of the simulation. This was made clear to participants before and after the simulation.

Five participants emphasised the value of this application as a learning intervention, indicating that they felt as if they had learnt a lot and that they understood the work, whereas with the textbook and videos, they struggled to understand how everything fit together.

Three of the participants indicated that they enjoyed the fact that the application challenged them, as they had not yet done something like it before. It helped them understand the purpose of the components and their location in a computer.

Table 6. Improvements

Suggested Improvements	Number Participants
Graphical texture quality	10
Navigation and better instructions	8
Bug fixes	3
Text quality	2
Boundary control and space	2
Faster loading	1
More challenging	1
Ventilation	1

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One participant complimented the effective navigation method using the controllers and the joysticks. This somewhat contradicts the issues previously mentioned, and could be investigated in future to determine what was different for this participant compared to the others.

The suggested improvements are indicated in Table 6. The first category of improvements relates to texture quality; ten participants indicated that the application would benefit from various graphical improvements, like anti-aliasing, improved texture quality, and better background and animation. While this is the ideal and will be integrated into future iterations, it is worth noting that increasing texture detail might cause the application to become non-functional on standalone HMDs like the Meta Quest 3. This will subsequently require more powerful computers, which is not ideal, as it will lead to extensive costs to purchase and set up gaming PC's to run the application. Future iterations will aim to balance performance and graphical quality as best as possible. One improvement that could benefit the application is the inclusion of animations to illustrate exactly how the components need to be applied in the correct spot.

For the navigational and better instruction, most suggestions were related to the fast response of the joysticks and the lack of training. As mentioned, this could be solved by a tutorial and demonstration, along with a lower turn speed on the joysticks while in the application.

The bug fixes referred to were those of the avatar and the components that 'fell through the ground', and the inability to pick up some of these components. To address this, the in-application colliders should be revisited to eliminate gaps between the colliders. As far as the picking up issue is concerned, a mechanism could be devised to return the component to its original position, indicating that the component was dropped in the feedback after completion. In this way, the user will be able to get hold of the component again, although losing a percentage of the marks for dropping the component.

Text quality is a difficult aspect since it scales with the participant's distance from the text – sometimes the participant needs to be very close. A possible workaround would be to increase the text quality significantly, but this will still only take effect within a relevant range of the text.

There were two users who wanted to stand up and walk around rather than sit and use the joysticks to manoeuvre the components. While ideal, this required a lot of space, which is often impractical. A possible alternative would be to incorporate teleportation rather than real-time movement.

With regards to the remaining suggestions, the faster loading time is a possibility, but would require optimisation of texture quality, which often leads to reduced realism. For the challenging part, it would be ideal to incorporate more advanced mechanisms as the technology improves, like applying the thermal paste and screws. Ventilation (when getting very hot while wearing the HMD and being immersed for a while) is not something that can be addressed from a development side, since it is a manufacturer-related issue.

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4.8 Combined Metrics

The radar chart [20] Fig. 3 provides an overview of all the metrics discussed. These metrics were summed for each type and converted to percentages. The VRSQ score in Fig. 3 was calculated as follows: (100 - the initial VRSQ score). This provided a positive value, so in this case, the higher the better. The NPS was calculated out of 200 since the score runs from -100 to 100.

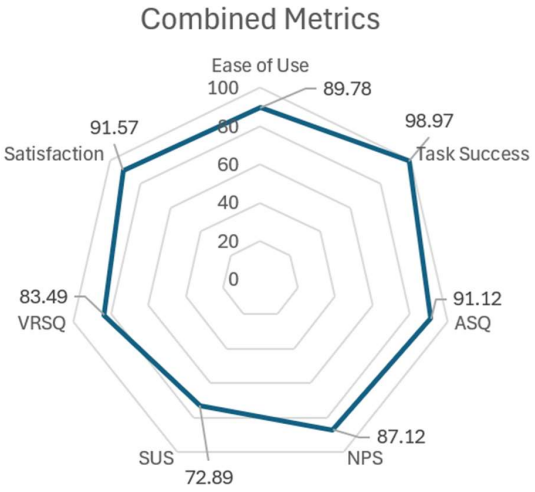


Fig. 3. Combined Metrics Radar Chart

When looking at the combined picture (Fig. 3), it seems that the application was considered very usable without the need for a lot of intervention; when compared to the issue encountered (Table 4) and suggested improvement (Table 6), it paints a different picture. One possibility is the novel effect that VR might have unlocked in the participants; a lot of participants were very excited since this was their first VR experience, and this could have skewed the data and brought in bias towards the novelty rather than the application itself.

5 Ethics

Ethical approval for this study was obtained under the ethical clearance number UFS-HSD2024/0146/5/6. All participation was voluntary, and participants could withdraw from the process at any time without negatively affecting relationships with the researchers.

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6 Limitations and Future Work

While the application proved usable, there were aspects that will need to be changed. Possible future work includes the improvement of the application based on the shortcomings identified here, and retesting it by first using experts and then students. The sample size was limited and, therefore, not very generalisable. Furthermore, more investigation is needed into the issues relating to the cause of the blank screens during the sessions. The fact that some participants used the controllers easily while others struggled is also a consideration for future research. Another possible future project would be to determine the actual educational benefit of using the application vs traditional textbooks and video demonstrations, since this study only focused on the usability and UX of the application. To measure the novelty effect and determine whether it is a possible issue, future research will have to be done over multiple cycles using the same participants to determine if constant exposure would decrease the usability of the application.

7 Conclusion

This study sought to address the high cost and physical fragility of computer hardware, which makes it difficult to give large groups of first-year students the hands-on experience they need. By developing a local, cost-effective VR application, the researchers aimed to bridge the gap between textbook theory and practical assembly. The results showed that the immersive technology is a usable solution that could offer a safe environment where students can experiment and learn without the risk of breaking expensive equipment.

The quantitative data highlighted the application's overall usability and UX. With an average SUS score of 72.89 (which exceeds the industry standard of 68) and an NPS of 74.23, the application is both usable and highly recommended by the participants. Further metrics confirmed the application's effectiveness, with an Ease-of-Use rating of 89.78%, an ASQ score of 91.12%, and overall Satisfaction at 91.57%. The VRSQ score remained low at 16.51, suggesting minimal cybersickness. Most participants found the tasks easy to complete, with success rates near 100% for most of the tasks.

The feedback also indicated that participants enjoyed the experience and felt it helped them understand how components fit together better than traditional videos or images. However, some feedback identified critical errors, such as components falling through the virtual floor and difficulties with cable management. While the novelty effect of VR likely might have influenced the high satisfaction ratings, the findings prove that this locally developed VR intervention is a usable and scalable alternative to traditional labs. This paper concludes that while technical refinements are needed to fix bugs and improve navigation, immersive VR shows promise for practising hardware assembly in resource-constrained educational settings.

Taking it all into consideration, the first iteration proved that a locally developed VR tool can be a powerful and affordable intervention for computer science and informatics students. While technical refinements are needed to fix bugs and improve navigation,

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the positive response from students suggests that VR can play a valuable role in computer science and informatics education if properly tested and implemented.

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Towards Developing Business Process Analyst Competencies through Higher Education Curriculum

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Abstract. Business process analysts (BPAs) play a critical role in organisational process management; however, they remain scarce, particularly in developing contexts such as Kenya. This study addresses the lack of a university-level course for developing BPA competencies aligned with Kenya's Vision 2030 strategy for business process outsourcing. Using design science research, we designed a course for prospective BPAs grounded in activity systems analysis and the 4I framework of organisational learning. The course was delivered to undergraduate students at a Kenyan university to develop key BPA competencies. This research contributes an empirically informed, industry-aligned course design, as well as prescriptive recommendations that universities can use to develop similar programmes.

Keywords: Business process analyst, Curriculum design, Activity systems, Organisational learning, Design science research.

1 Introduction

The business process analyst (BPA) is a mid-level person who deals with discovering, validating, documenting and communicating business process knowledge [1]. Studies note the importance and scarcity of the BPA role in organisations, particularly in Africa [2-4]. Often, the BPA role is passed on to business analysts (BA)s who then require additional training [5]. Competency has been regarded as the skill as well as the attitudes that are associated with performing optimally within a particular job [6]. The link between competency and pedagogy is "inextricable*"* and forms a basis for the development of a common curriculum [7].

The required BPA competencies could be developed at a Higher Education Institute (HEI) [7]. Yet HEIs face challenges meeting industry demand [8]. There is a need to continuously evolve IS curricula and pedagogy [7] and to develop students ready to work effectively aligned to industry requirements [9-11]. To develop dynamic curricula, a variety of approaches have been used such as including hands-on approaches [12-14]. Substantial literature supports industry collaboration with embedding industrial knowledge into curriculum and industry-based projects [9, 15].

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This study looked at building competency for a relatively new role in Kenya, that of the BPA. Kenya has developed a long-term strategy, the Vision 2030, which outlined a plan for growth in Business Process Outsourcing where Kenya hopes to be a global hub for process offshoring [16]. However, high-quality process offshoring is achieved through BPM (Business Process Management) [17, 18] and involves the ability to analyse and redesign business processes [19], a key role of the BPA. Studies have indicated that skills deficits and organisational capabilities are a dominant barrier to Kenya process offshoring [20] and in agriculture [21]. Yet in a prior study the authors confirmed no BPA curriculum suited to the Kenyan context and that the BPA competencies required in Kenya varied from those of South Africa [22], highlighting the importance of local context. This paper therefore develops and describes an artefact (a course) that HEIs can use to develop similar courses. This paper aims to answer the research question: How can HEI curriculum and pedagogical interventions and interactions develop student BPA competencies required in Kenya?

This paper first introduces some literature on BPA competency development, the Design Science Research (DSR) Method (DSRM) used follows, then the problem identification and motivation for the development of the artefact. The objectives and design of the artefact using activity systems analysis are presented, followed by demonstration and evaluation of the artefact, before concluding.

2 Prior Work on Developing BPA Competencies

Studies have defined BPA competency requirements as beyond those of a BA [5, 23]. The BPA should have strong technical, business and mathematical competencies (left brain thinking) as well as strong interpersonal skills involving emotional intelligence and being able to communicate effectively with stakeholders (right brain thinking) [23, 24]. Competency frameworks for BPAs had been developed prior to this study [2, 25, 26]. Since our empirical research, Artificial Intelligence (AI) has transformed most roles, for example capabilities needed include embedding intelligent decisions [27]. Practitioners must design how AI agents, humans, and systems collaborate, yet BPMN (Business Process Model and Notation) remains core, even for AI Orchestration [28].

When developing competencies through curriculum it is important to understand the process by which students move from superficial learning to reflexive and reflective learning [29]. The 4I Framework of Organisational Learning [30] encompasses key elements of organisational learning such as the exploration and exploitation characteristics of organisational learning; enabling the assimilation and the use of the knowledge that has been learnt [31]; that learning takes place across three levels within organisations (individual, group and organisational) [32]; and acknowledging the importance of intuitive and experiential learning processes. The model has four main processes: intuiting, interpreting, integrating and institutionalizing that are linked to the three levels of organisational learning. We used the 4I framework in a prior study to established BPA competencies required in Kenya [22]. These are listed in Table 1, with the mean importance, where 5 indicates extremely important, and 1 not important at all. In a second

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study we used the 4I framework to identify organisational interventions that develop BPA competencies [33]. The mapping is presented in Table 1.

Table 1. Organisational interventions and processes to develop BPA competencies.

BPA Competency	High Impact Interventions (Process)
Business Fundamental Competencies (BFC) (3.9)	
Business Analysis (BFC1) (3.9)	On-the-Job (DIY) intervention (Intuiting) Knowledge sharing (Institutionalizing) Staff-to-Staff mentorship (Interpreting) Inter-Group collaboration (Integrating)
Holistic Overview of Business Process Thinking (BFC2) (3.9)	On-the-Job (DIY) intervention (Intuiting) Staff-to-Staff mentorship (Interpreting)
Client Experience Thinking (BFC3) (4.2)	On-the-Job (DIY) intervention (Intuiting) Organisation run training (Institutionalizing)
Mathematical and Statistical competency (BPC4) (3.0)	Organisation run training (Institutionalizing) Vendor Certifications (Integrating)
Business Interpersonal Competency (BIC) (4.0)	
Facilitation and Leadership (BIC1) (3.8)	Organisation run training (Institutionalizing)
Business Requirement Elicitation (BIC2) (3.6)	On-the-Job (DIY) intervention (Intuiting)
Business Communication (BIC3) (4.3)	Organisation run training (Institutionalizing)
Trustworthiness (BIC4) (4.3)	Organisation run training (Institutionalizing)
Organisational Knowledge (OK) (3.8)	Staff-to-Staff mentorship (Interpreting) Organisation run training (Institutionalizing)
Business Process Orchestration (BPO) (3.7)	
Business Process and Value Chain Modelling (BPO1) (3.7)	On-the-Job (DIY) intervention, (Intuiting) Inter-group collaboration (Integrating)
Business Process Improvement (BPO2) (3.9)	On-the-Job (DIY) intervention (Intuiting)
BPM risk and compliance assessment (BPO3) (3.9)	Knowledge sharing (Institutionalizing)
BPM drive and Promotion (BPO4) (3.4)	On-the-Job (DIY) intervention (Intuiting)
Technical Competencies (TC) (3.2)	
Service Oriented Architecture (TC1) (3.0)	Inter-group collaboration (Integrating)
ERP systems knowledge (TC2) (3.2)	Inter-group collaboration (Integrating)
User Interface Design (TC3) (3.2)	Knowledge sharing (Institutionalizing)

Activity theory has been used widely in HEI learning and course design [34] and in student learning processes [35]. It has been used with other learning theories like experiential learning, in expansive learning and work re-designing [36]. Activity systems analysis which uses some activity theory is an approach developed by Engeström [37] which has been used in design-based research [34, 38, 39]. Activity systems are a means of understanding human activity within a collective context often represented in the form of triangle diagrams [34, 37, 40-42]. Researchers should engage in reflection with iterative drafting and redrafting of the activity system triangle models [34]. While real-world contexts are more complicated than what can be represented in triangle diagrams, activity systems are useful in representing participant's worldview of a given context [34]. Activity systems can occur over a plane of analysis that includes the individual, inter-individual and institutional plane [34]. This is similar to the 4I framework of organisational learning that describes learning processes across the individual, group and

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organisational levels [30]. Moreover, activity systems analysis has been described as beneficial to design-based research by enabling the identification of meaningful activity units and identification of existing tensions in the activity systems [34].

3 Method

DSRM followed [43] comprises phases which progress iteratively: the problem identification phase, the defining of objectives, artefact creation and demonstration, and artefact evaluation [43]. The problem and solution were seen as novel to Kenya so conceptualizing the problem and designing the solution was done empirically. The problem conception was published in a prior paper [22] as well as the empirically derived design principles mapping competencies to interventions [33]. For the design, we held one focus group discussion with 10 Kenyan students (S1-S10) doing business and information technology related courses. Since there were no lecturers teaching BPM in Kenya, we interviewed four South African lecturers (L1-L4) with experience teaching BPM courses. The course design was informed by the derived mappings in Table 1, these interviews and by the AIS/AIC curriculum guidelines for undergraduate [44]and postgraduate programs [45, 46]. Prior to any data collection, the researchers sought ethical approval from their HEI ethics committee. During the interview phase of this study, each participant was provided with a consent form. All participants were made aware that they had the right to withdraw from interviews at any point. All survey and interview responses were kept confidential and participants remained anonymous.

The artefact was instantiated in the form of a BPM course run for students doing a Bachelor of Business Information Systems in a Kenyan HEI. The course ran across 2 semesters with 2 separate cohorts. Each semester ran for 12 weeks. The students were 4th-year students undertaking an undergraduate degree in Business and Information Technology. The first cohort attended the course from April-July 2018 and the second cohort from August-November 2018.

The Framework for Evaluation of DSR (FEDS) was used for artefact evaluation [47]. The evaluation was summative, using a survey focusing on the extent to which the students found the requisite BPA competencies useful in the course (Fig. 1). We argue if they found the competencies useful in the course then to an extent the course developed them. A pilot survey ran in June 2018. The questions were adjusted and the final survey ran with the second cohort in October 2018. Out of the 110 students in the course, 57 responded to the survey (52%). Please contact us for the full survey.



Fig. 1. Extract of student survey

Design principles are often extracted from DSR artefacts. In our study we felt the Kenyan domain needed exploring and conceptualisation as the problem was perceived

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as novel. The solution domain was also relatively novel and hence creativity was needed. In these cases high value is placed on instantiation and artifact description and less on contributions to design knowledge [48, 49]. Therefore, we felt no further design principles needed to be abstracted to justify a research contribution.

4 Problem identification and motivation

We found no literature that discussed BPM or the BPA role within the Kenyan context. In a prior related study we surveyed Kenyan BPAs [50] confirming that some had done a course related to BPM as part of organisation run training but none as part of any HEI programme. They confirmed there were no formal courses in Kenya that extensively delved into BPM concepts, the BPA role and competencies required for the role. There was a clear indication, that BPAs had experienced a steep learning curve from when they began their role: *"you have to understand what is an ERP system, then understand what SAP is, how does it now come to fit into the Processes. So, it has actually been…very steep." (BPA1)*

They argued that nothing significantly relevant to BPM and ERP systems had been taught to them at their respective HEI: *"but when it comes now to the System Analysis, Business Processes side of it, especially when you're talking about ERP systems, we're not there yet. I haven't found a college or a university that offers something specific or close or directly related to ERP systems… you have to go back now to SAP Company or Oracle Company to be taken to one of their academies" (BPA1).*

The interventions to build BPA BPM competencies came at a significant cost: *"So, still in Kenya or in Africa it becomes a very expensive venture even for us as a Company or as an industry...SAP training is very expensive. I know in other parts of the world they offer ERP systems units like SAP for example at the university level." (BPA1); "Business process analysts apparently are very willing to learn, but they are restricted because of the training costs that the company has to incur" (BPA8)*

Hence, we identified the need for a BPM course at a HEI in Kenya. The problem was seen as unique to Kenya as the need for BPM knowledge in Kenya was driven by their BP offshoring strategy [16] and the recent increase in enterprise system (especially from SAP) implementation projects, potentially different to other countries.

5 Defining objectives of the solution

To develop requirements for a potential BPM course, we used activity systems analysis to map insights provided by the lecturers on how they tailored their BPM courses.

The subject concept. The subject defines the attributes of the individual or group that acts or causes the activity. Courses were taught to students in their third or fourth year of the undergraduate program: *"This is a third-year program we expect them to have gone through a second-year Information Systems course which covers Systems Analysis and Design and implementation" (L1).* Lecturers also provided an indication of skills

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that the students were required to have before the BPM course: *"Coding is necessary, because when we move into the BPM space, they're first of all modelling, but at the same time we're relating how a process model might be realized through multiple use cases" (L1).* Lecturers emphasized that developing having both practical and theoretical components are essential: *"we hold back a little bit on the technology front and we introduce them to what is a Business Process, what is Process Analysis, how can you analyse a process, techniques about analysing a process, BPMN, how to map a process and then we start introducing them into the technology…an Enterprise System" (L2).*

Sourcing the required tools or instruments. The human tools were identified as lecturers, tutors or lab assistants: *"Usually, tutors are students who have previously done the course, but also we encouraged that they should have also done TERP 10 certification at least, and we monitor their performance" (L2).* ICT tools were used during the classroom session by the student attending the class or the human facilitating the class: *"the students learn not just to model a process using the BPM notation but to also execute automated process within the Bizagi Suite" (L1).*

Identifying and defining the Object/Objective. The objective is achieved through the student, an implemented teaching methodology and through human and ICT tools. Some of the objectives include learning BPM concepts and the ability of the student to reflect on learning. For the course to achieve its objective, students needed to understand and synthesize BPM concepts taught in the classroom, reflect on these and carry out hands-on assignment and project work: *"we're doing a project at the moment with a health clinic…where we're almost moving through a BPM process with the students as a research project but also hopefully with some more practical benefit for them to implement certain process improvements… it's that research project-based idea and then using BPM as a way to actually engage in research project work with them" (L1).* One lecturer identified the importance of ICT tools specifically ERP systems software in helping students understand BPM both theoretically and practically: *"The other thing is, of course, the ERP systems software with the course, it's developed very well and through this, there is a good relationship between what we are learning theoretically. It has become easy to understand the processes" (L4).* Besides analysing BPM on a theoretical and practical level another critical objective was enabling students to reflect on what they had learnt. *"Section of their project submission requires them to reflect...hopefully it helps them going forward, but in any case, I think that's the aspect that if a student would really learn how to appropriately reflect it would significantly improve their ability to absorb the learning" (L2).* A lecturer emphasized that for students to do well in the course they were required to fully understand why they had to complete certain milestones. The students were dissuaded from cramming to pass the course. *"It's not the kind of course where you can just cram for an exam… because of those deliverables, those project deliverables" (L1).*

Developing the necessary learning artefacts. The learning artefacts included class assignments and projects completed by students and a repository of questions compiled

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by lecturers. The students were required to apply their own solutions to problems presented during assignments and projects, as stated by L2: *"The project involves going to the industry, get a Business Process, analyse it, interact with people, gather data and draw that process, present it to us, get feedback and make a recommendation, use technology, use SAP, use everything to figure it out."* A repository of questions was created for a specific learning session. Through this repository, students were able to practice what they have learnt and provide solutions to the problems described in the questions and exercises: *"we've even gotten a book that's to be published and it's going to cover further information about the course… when I got to the course in 2014 there was very little on BPMN. So, now I've been able to create new questions" (L3).*

Defining the rules for assessing the student (subject). Rules act as the main mediation process between the community such as the lecturers, HEI, industry and the student. Rules are the criteria for assessing the performance of students for a given activity. Students were evaluated on their lab work, continuous assessment tests and a semester project. These were evaluated by the lecturer through a previously prepared marking scheme: *"these small exercises which are part of class work will usually hold about 10% of the total required score. Then they're also required to do two-semester tests, and these two-semester tests carry 80% of the total course work" (L3).* Besides assignments, the lecturers gave students a semester-long project based on the process lifecycle. The project involved interaction with business owners. Students apply theoretical concepts learnt in class within a real-life industry environment: "*the other practical aspect of the course is obviously the project which students have to work on the practical project, here's another component of practical that's embodied in the project, so it probably comes down to 50/50" (L2).*

Defining the major stakeholders and responsibilities (Division of labour). Division of labour addresses the roles and responsibilities of different stakeholders in the course. Stakeholders included lecturers, students, industry and software vendors. Industry players provided industry and software vendor learning resources; students were responsible for completing classroom activities; lecturers were responsible for preparation and evaluation of class activities. Industry and vendor learning resources or experiences were useful for students in terms of real-world exposure: *"We have a formal internship program in our Honours year… Some of the students yes will go off in that internship and there may then be an environment where they would apply more of the BPM skills" (L1).* As critical stakeholders, students had to use the resources and knowledge available to them to enhance their skills and competencies. Students are provided with the necessary means for a learning activity, it is their responsibility to use these means: *"students should have an open mind and more willing to learn new technologies" (S1).* Lecturers must keep up to date with trends in BPM and remain proficient in the relevant areas. The lecturer also must plan and implement learning activities: *"I'm deciding on what that would be, so I'm deciding whether we're going to do the vacation leave request exercise this week or the loan request exercise" (L2).* Vendor learning resources were part of the division of labour. In some cases, vendors help create learning

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environments for competency building for students and lecturers: *"SAP obviously we work very closely with them, they provide the support to allow us, through their University Alliance Program, to access their technology and make effective use of it in a teaching environment because that's the biggest challenge, really it's a big expensive technology and using it in class requires sometimes a lot of resources" (L2).*

Defining the learning environments for the course (Community). The community is the environment within which the learning activity takes place. This would happen within an HEI but also encompass interaction with industry and software vendors. HEI resources include library facilities, classrooms and laboratories. Curriculum documents describe the learning environment: *"Project team laboratories to accommodate team projects are essential to the IS program. Classrooms equipped with computer projection, Internet, and local network access, and appropriate computing and software infrastructure" [44].* The learning environment extended to external learning environments including industry interactions and software environments provided by BPM vendors. These are available when the HEI has a relationship with industry and vendors: *"there's usually support from vendors" (L2).*

6 Design of the artefact

At the design stage, we determined the applicability of each of the concepts of Activity systems and the resources required to achieve the objectives. The course blueprint was developed based on 4 activity systems representing the 4 processes of the 4I framework namely intuiting, interpreting, integrating and institutionalizing. The intuiting activity system (Fig. 2) was designed to focus on how students would learn in the course through learning on the job. The design was for students to proactively learn with limited direction. The intuiting activity system was designed to have the highest impact on developing BPO4, BFC1, BPO1, BPO2, BIC2, and BFC3 competencies**.**

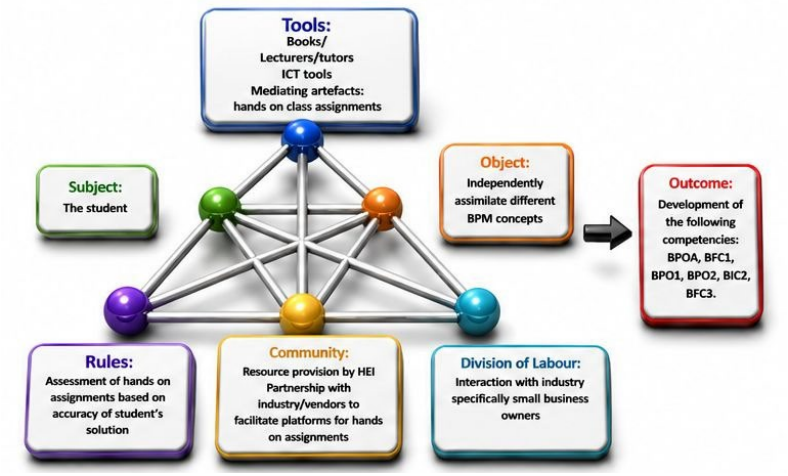


Fig. 2. The intuiting activity system design

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The interpreting activity system (Fig. 3) shows how students would learn in the course by observing process owners as they completed specific tasks (job shadowing) and through mentorship from tutors and their fellow students (student to student mentorship). Hence to learn by observation and from their peers. The interpreting activity system was designed to have the highest impact on developing BPO4, BFC2, TC2, and BFC4 competencies. The integrating activity system (Fig. 4) represents how students would learn through collective action including teamwork. The activity system incorporates external consultants who give guest lectures; intergroup collaboration (80% of the coursework was designed for group work); and interacting constantly with the small business owners during the semester project. Top management buy-in was critical, in this case through the Dean and academic director of the faculty running the BPM course. They needed to support a more flexible timetable for the students to allow them to spend more time on the semester project. Top management would facilitate embedding the BPM course into the undergraduate curriculum. The integrating activity system included enabling students obtaining BPM related vendor certifications if they wished to go deeper into the BPM domain. This activity system was designed to have the highest impact on developing BPO4, BFC2, TC2 competencies.

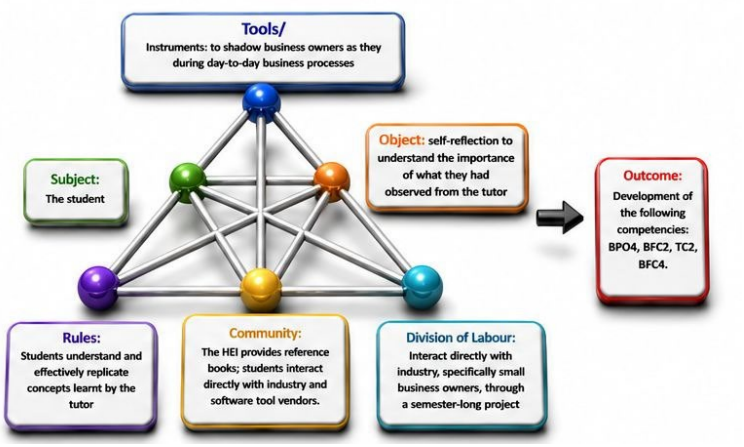


Fig. 3. The Interpreting activity system design

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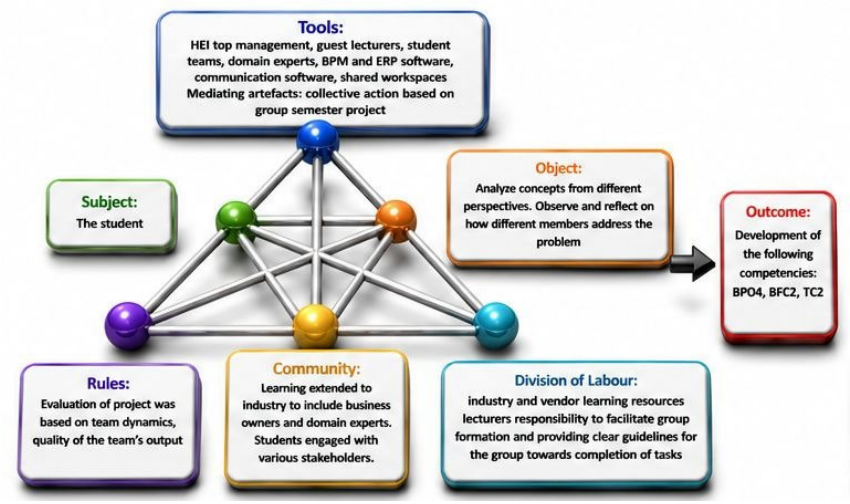


Fig. 4. The Integrating activity system design

The institutionalization activity system (Fig. 5) was designed to address student learning through well-established routines or structures and clearly outlined rules and procedures. The learning process focused on the lecturer having structured patterns of interaction and communication with students. It focuses on the collection of knowledge at individual and group level and involves preparation of HEI approved student assessment guides, course outlines and marking schemes for all coursework and assessments, formalized lecturing sessions and workshops with students and development of a knowledge sharing platform. This activity system was designed to have the highest impact on developing BIC3, BIC1, BFC4, OK, and BIC4 competencies.

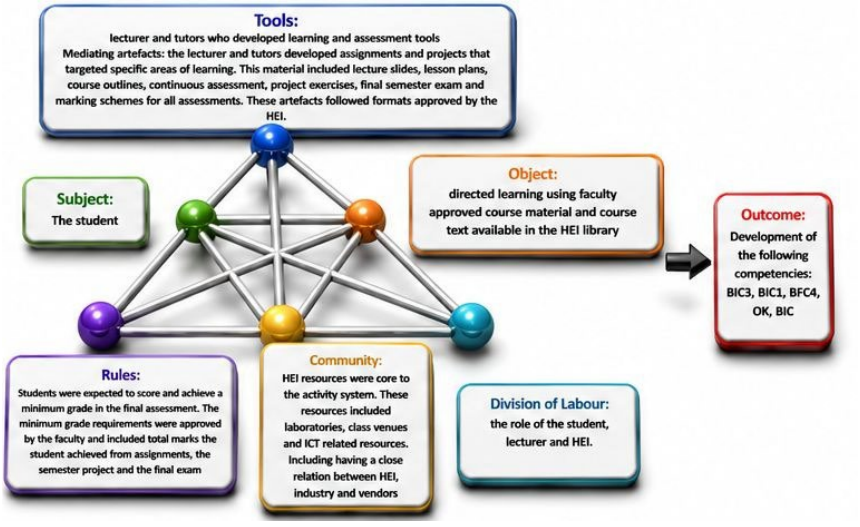


Fig. 5. The institutionalizing activity system design

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7 Demonstration and instantiation of the artefact (the course)

Using the designed activity systems as a guide, and in conjunction with industry collaborators and lecturers working within the HEI, the material was designed, textbooks were used to compile lecture notes, group assignments and practical lab work was designed. Table 2 describes how the course was run.

Table 2. The activity systems and specific interventions.

Week	Activity system	Intervention(s)
1-2	Intuiting	On-the-job-DIY: a hands-on approach to 5 modelling exercises
1-2	Interpreting	Student to student mentorship: tutor support in the modelling exercise
1-2	Integrating	Inter-group collaboration: group interaction for the modelling exercises and a semester project; External consultants: guest lecturer from software vendor invited to the class
1-2	Institution-alizing	Structured learning (Establishment run training): Lectures sessions prepared by the lecturer. Knowledge sharing: Online portal to access and share course material.
3-4	Institution-alizing	Structured learning (Organisation run training): Lectures sessions prepared by the lecturer; Knowledge sharing: Online portal to access and share course material.
3-4	Integrating	Intergroup collaboration: Formation of student groups as part of a semester project; Stakeholder engagement: student interaction with small business owners; Top management support: approval of course outline by faculty academic director
5	Intuiting	On-the-job: individual assessment during the sit-in test
5	Integrating	Inter-group collaboration: completion of the AS-IS model as a group
5	Institution-alizing	Student (employee) assessment: pre-determined assessment criteria to grade students' sit in assessment tests
6-7	Interpreting	Job-shadowing: students observed process owners as they executed a specific business process
6-7	Integrating	Stakeholder engagement: students made visits to their selected businesses to collect relevant information on the business process; Inter-group collaboration: students carried out exercise 3 as a group
6-7	Institution-alizing	Structured learning: lecture sessions were prepared and disseminated by the lecturer using the HEIs approved format
8-9	Intuiting	On-the-job: individual assessment during the sit-in test
8-9	Integrating	Inter-group collaboration: completion of the TO-BE model as a group; Stakeholder engagement: student groups providing recommendations to small business owners on how to improve their business process
8-9	Institution-alizing	Student (employee) assessment: pre-determined assessment criteria to grade students' sit-in assessment tests
10	Intuiting	On-the-job: individual assessment during the final exam
10	Integrating	Inter-group collaboration: completion of the semester project as a group
10	Institution-alizing	Student (employee) assessment: pre-determined assessment criteria to grade students' sit in assessment tests; Knowledge sharing: upload of student projects onto online portal for reference by future BPM students

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8 Preliminary Evaluation of the BPM course (the artefact)

Table 3 presents the mean and rank results from the BPM students who completed the second survey. The usefulness (in the course) of each competency to students is compared to the prior importance of the competency given by practicing BPAs (Table 1). Students found all BPA competencies to be useful in completing the BPM course. Using the competencies in the course provided preliminary validation that the design and demonstration met its objectives and was coherent. The business analysis competency (BFC1) was seen as the most useful, while Mathematics and statistical competency was the least useful. Students perceived business requirements elicitation competency (BIC2) slightly more useful than business process improvement competency (BPO2). This is likely because the students spent a considerable amount of time collecting business requirements from the small business owners during process analysis. Due to time constraints and given that this was the first time the course was run, business process improvement work was done mainly on a theoretical level, and students were only required to give recommendations to the small business owner on areas of the process they could improve. In the future, the course can be extended to enable students to implement their recommended process improvements with the small business owners. Furthermore, the results confirmed that holistic overview of business thinking (BFC2) while useful had insufficient focus relative to importance (-10 rank difference). This prompted adjusting the course to include a section that addressed usefulness of understanding the entire functions of the selected business. Table 4 outlines the final prescriptive statements for the BPM course. These were abstracted from the final course after 2 iterations.

Table 3. BPM Course Usefulness (3 is "Neutral" and 5 "Extremely useful") contrasted to BPA importance ranking (Table 1)

Competency N=57	Mean (Usefulness)	Useful Rank	BPA Importance Rank	Rank Difference
BFC1-Business Analysis	4.51	1	4	3
BFC2-Holistic Overview of business thinking	3.93	15	5	-10
BFC3-Client Experience Thinking	4.46	3	3	0
BFC4-Mathematical and Statistical competency	3.78	16	16	0
BIC1-Facilitation and Leadership	4.14	10	8	-2
BIC2-Business Requirements Elicitation	4.42	4	11	7
BIC3-Business Communication	4.3	7	2	-5
BIC4-Trustworthiness	4.34	6	1	-5
BPO1-Business process and Value chain modelling	4.47	2	10	8
BPO2-Business Process Improvement	4.35	5	7	2
BPO3-Business Process Risk &Compliance Assessment	4.18	9	6	-3
BPO4-BPA drive and promotion	4.07	12	12	0
OK-Imp-Organisational Knowledge	4.07	12	9	-3
TC1-Service Oriented Architecture	4.2	8	15	7
TC2-ERP systems Knowledge	4.12	11	13	2
TC3-User Interface design	4.07	12	14	2

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Table 4. Recommended implementation of designed activity systems (prescriptive statements)

Activity system	Intervention	Recommended implementation within HEI (Prescriptive statements)
Intuiting	On-the-Job	All students to undergo an individual assessment represented as a continuous assessment test. All students to complete 5 lab exercises. All the exercises to require hands-on problem-solving using a process modelling tool.
Interpreting	Student to student mentorship	The lecturer is to plan tutor sessions during the modelling exercise and to promote consultative meetings between students when solving problems within their groups.
	Job shadowing	As part of the semester project, students are to observe, and record steps taken by process owners as they execute specific business processes.
Integrating	Intergroup collaboration	Students are to form groups as part of the semester project. For the project, students are required to analyse and redesign specific business processes of a small business owner.
	Stakeholder engagement	Students are to interact with small business owners to analyse and redesign their business processes. Students are to visit their business to collect relevant information on the business process
	Top management support	The lecturer is required to get top management support, for all course content of the BPM course. This is to be done through the director's approval of a course outline.
	Vendor software tools	The student groups are required to use modelling tools to model the AS-IS and TO-BE models for the semester project.
	External consultants	The lecturer is to invite guest lecturers with strong backgrounds in BPM/ERP from industry or from specific software vendors.
	vendor certifications	The lecturer is to incorporate vendor certification learning material especially certifications for BPM and ERP systems.
Institutionalizing	Knowledge sharing	A Learning Management System (LMS) to be set up for students to access and share course material. The lecturer is to upload past student projects for reference by future BPM students.
	Organisation run training	The lecturer is to prepare structured learning sessions. These lecture sessions are to be disseminated using the HEIs approved format and approved core text. The lecturer's material is to be stored on the LMS of the HEI.
	Employee Assessment	The lecturer is to prepare the student's assessment criteria. The lecturer is to grade students' tests, semester projects and exams

9 Conclusion

This DSR study provides practical and theoretical contributions. Organisations in Kenya face significant costs developing BPA competencies through expensive training and vendor certifications. This study provided a practical contribution by developing HEI curriculum to develop BPA competencies in Kenya, aligned with the country's business process outsourcing strategy and increase in ERP implementations. From a theoretical perspective, activity systems analysis and the 4I Framework of Organisational Learning were mapped to competences, the resulting four activity systems and sixteen recommendations provide HEIs with a theoretically informed approach to BPA competency development. Evaluation across two semesters demonstrated the

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effectiveness of integrating hands-on exercises, industry collaboration, and structured assessments. Hence the main contribution is the activity systems which explain how the relevant competencies can be developed.

The research has limitations suggesting future directions. The Echelon approach of DSR argues that different phases of DSR can be considered independent research contributions [51] and this paper represents the design and initial demonstration and evaluation of the course. The changes to the course between iterations are not described, the evaluation has concerns and design principles are not clearly extracted. The evaluation by students of the usefulness of each competence in completing the course shows that these competencies were used in the course which we believe validates the design and demonstration but arguably does not confirm that their competence levels increased through the course. This would require pre and post measures and assessments which were not completed. The evaluation captured immediate student perceptions rather than long-term outcomes or perceptions from employers whether competencies had improved per cohort. The empirically derived competence mapping provides design principles that are transferable to other context and courses but we did not extract further design principles from our actual course. Without clearer design principles, the instantiation at one institution limits generalizability, requiring validation across multiple institutions and contexts. Activity theory has strong notions of contradictions and tensions and these tensions (between industry requirements and HEI capacity, between theoretical instruction and practical experience) could give course design principles explanatory power and transferability. More importantly some time has passed since the study was completed and the advent of AI has meant that the importance of some competencies has changed. Future research with improved evaluation or longitudinal studies tracking graduate career progression would strengthen understanding of real-world impact. In addition, adaptations of the course design for different educational levels and how emerging technologies like process mining and AI-enhanced BPM can be integrated into curriculum design is needed. Finally stronger theoretical framing such as the use of activity theory to extract design principles from courses is recommended.

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Rethinking Presence in ODeL: Extending the Community of Inquiry Framework with Quasi-Presence in the Context of Generative AI

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Abstract. The development of higher-order cognitive skills (HOTS), including critical thinking and reasoning, is a critical component of graduate education, particularly within Open Distance e-Learning (ODeL) environments where structured support is required to guide academic engagement. The Community of Inquiry (CoI) framework conceptualises meaningful learning through the dynamic interaction of the core presences of teaching presence, social presence and cognitive presence; however, its assumption of equal contribution of presence warrants reconsideration in ODeL environments. This study establishes a baseline understanding of graduate students' educational experiences of HOTS development in a Computer-Supported Collaborative Learning (CSCL) environment in ODeL. A mixed-methods approach was followed, combining quantitative analysis of a CoI survey (N=82) with qualitative data from two focus group discussions. The findings reveal a moderate relationship between teaching presence and cognitive presence, while social presence showed a weaker association and did not significantly predict cognitive presence. These results suggest that the balance of presences may be context-dependent rather than inherently uniform. Building on this baseline, the paper argues that Generative Artificial Intelligence (GenAI) introduces a form of quasi-presence that can augment cognitive processes and redistribute elements of teaching presence. The paper contributes by introducing the concept of quasi-presence as a means of conceptualising AI-mediated learning interactions and provides a foundation for future CoI-informed research in AI-mediated ODeL environments.

Keywords: higher-order cognitive skills· Community of Inquiry· ODeL· CSCL· generative artificial intelligence

1 Introduction

The development of higher-order thinking skills (HOTS) [1], often associated with the upper levels of Bloom's Taxonomy (analysis, evaluation, and creation) [2], is essential for deep learning, problem-solving, and meaningful academic engagement. In graduate education, particularly within research-intensive disciplines, these skills underpin students' ability to engage critically with knowledge,

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synthesise information from multiple sources, and contribute to academic discourse [3]. Such capabilities are often demonstrated through practices such as argumentation, where students construct, justify and communicate well-reasoned arguments. However, the development of HOTS remains challenging in Open Distance e-Learning (ODeL) environments, where students frequently operate with limited face-to-face interaction and require structured support to guide their learning processes [4].

In response to these challenges, Computer-Supported Collaborative Learning (CSCL) environments have been adopted to facilitate interaction, collaboration, and knowledge construction among students that are geographically dispersed [5]. Within CSCL, the Community of Inquiry (CoI) framework has emerged as a model for understanding meaningful learning experiences, conceptualising them through the interaction of the three core presences [6].

The CoI framework has been applied in online and blended learning contexts and assumes a relatively balanced interaction between the core presences in supporting meaningful learning [4]. However, emerging evidence suggests that this balance may not always be realised in ODeL environments, particularly at graduate level, where students may rely more heavily on structured guidance and scaffolding from e-moderators (supervisors) than on peer interaction [1]. In such contexts, the relative contribution of each presence to the educational experience warrants closer examination.

At the same time, the rapid integration of generative artificial intelligence (GenAI) into educational settings is reshaping how students engage with content, feedback, and knowledge construction [7]. GenAI is an umbrella term for a large and ever growing set of artificial and augmented intelligence (AI) tools and has been identified as ".. a technology that (i) leverages deep learning models to (ii) generate human-like content (e.g., images, words) in response to (iii) complex and varied prompts (e.g., languages, instructions, questions)" [8, p.2]. In the education space, GenAI tools are increasingly used to support tasks such as idea generation, drafting, and refining academic arguments, thereby influencing both the cognitive processes of learners and the nature of instructional support [9]. This introduces a new layer of interaction within ODeL environments that is not explicitly accounted for within the CoI framework. Taken together, these developments raise important questions about how teaching, social, and cognitive presence are enacted in ODeL contexts, and how these presences may be reinterpreted in the presence of AI-mediated support.

The study is guided by the following research questions: *To what extent do the core presences function as a balanced framework in ODeL environments?* This is further explored through the following sub-question: *How can the concept of presence be reconceptualised in the context of GenAI?* To address these questions, the study examines graduate students' educational experiences of higher-order cognitive skills development in an ODeL context. In doing so, the study establishes a baseline understanding of how teaching, social, and cognitive presence function within an ODeL context in the absence of AI-mediated support. In this paper, a graduate student refers to a student who has completed an undergrad-

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uate qualification and is enrolled in a research-course in an honours or advanced diploma programme. Adopting a mixed-methods approach, the study combines quantitative analysis of a CoI survey with qualitative insights from focus group discussions to investigate the relative contributions of the core presences. The findings indicate a moderate relationship between teaching presence and cognitive presence, while social presence plays a more limited role in supporting HOTS development.

The contribution of this paper is twofold. First, it provides empirical evidence that questions the assumed balance of teaching, social, and cognitive presence in ODeL contexts. Second, it proposes augmenting the CoI framework by introducing the concept of quasi-presence to account for AI-mediated learning interactions. These contributions have implications for the design of ODeL using CSCL that aims at supporting students' educational experiences in graduate-level contexts in the presence of GenAI.

The remainder of the paper is structured as follows. The literature review focuses on higher-order cognitive skills in ODeL environments, the CoI framework, and emerging perspectives on GenAI in education. This is followed by the methodology section, which outlines the research design, participants, data collection, and analysis procedures. The findings section then presents the quantitative and qualitative results of the study. The discussion section interprets these findings in relation to the CoI framework and introduces the concept of quasi-presence. Finally, the paper concludes by summarising the key contributions, outlining the assumptions and limitations of the study, and identifying directions for future research.

2 Literature Review

2.1 Higher-Order Cognitive Skills in ODeL Environments

HOTS, including critical thinking, reasoning, and the ability to construct and apply knowledge, are widely recognised as essential outcomes of higher education [5]. At graduate level, these skills enable students to engage critically with academic knowledge, synthesise information from multiple sources and demonstrate deeper levels of understanding through reflection and application. However, the development of HOTS in ODeL presents specific challenges [4]. Students often engage with learning materials on their own, with limited opportunities for sustained interaction with their peers and fast turn-around feedback [7]. As a result, the development of complex cognitive processes requires carefully designed learning environments that provide structure, scaffolding, and opportunities for guided engagement [10].

In ODeL, CSCL environments have been identified as a means to support the development of HOTS by enabling interaction, shared knowledge construction, and engagement with multiple perspectives [6]. Within such environments, structured activities and scaffolded tasks can guide students through processes of inquiry, reflection, and integration, supporting deeper cognitive engagement [6].

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The effectiveness of these environments is influenced by how learning interactions are facilitated and experienced by students. In particular, the extent to which instructional guidance, peer interaction, and individual reflection contribute to cognitive engagement remains an important consideration in ODeL contexts [10].

2.2 The Community of Inquiry Framework

The CoI framework conceptualises meaningful learning as the interaction between the core presences of teaching presence, social presence and cognitive presence [11]. Importantly, it is not only the individual presences that contribute to the educational experience, but also the intersections between them. As illustrated in Fig. 1, the overlap between social and cognitive presence represents *supporting discourse*, where learners engage in dialogue that facilitates meaning-making. The intersection between social and teaching presence reflects the *setting of climate*, where trust and a sense of belonging support engagement. Similarly, the overlap between teaching and cognitive presence is represented as *selecting content*, which can be understood more broadly as *regulating learning* [5], where instructional design and facilitation guide students towards deeper levels of understanding. At the centre of these intersecting presences lies the *educational experience*, which emerges from their dynamic interplay, highlighting that meaningful learning is derived from integrated and mutually reinforcing relationships rather than isolated elements.

Recent CoI research suggests that the relationships between teaching, social, and cognitive presence are not uniformly distributed across online learning environments. Teaching presence often demonstrates a stronger influence on cognitive engagement and learning satisfaction than social presence, particularly through its role in facilitating cognitive processes and learner engagement [12–14]. Furthermore, the relative contribution of each presence appears to vary across course modalities, instructional designs, and levels of learner self-regulation, suggesting that the enactment of CoI presences may be context-dependent rather than inherently balanced [15–17]. In structured ODeL environments, where students frequently rely on instructional design, facilitation, and feedback, teaching presence may assume a more prominent role, while opportunities for peer interaction may be comparatively limited. These observations suggest that the contribution of CoI presences may vary according to contextual factors such as learning design, modality, and learner characteristics, raising questions about how presence should be understood in increasingly technology-mediated learning environments.

2.3 Reconsidering Presence in ODeL Contexts

The emerging evidence discussed above suggests that the relative contribution of CoI presences may vary across educational contexts. This observation becomes particularly relevant when considering the emergence of GenAI, which introduces new forms of interaction that are not explicitly accounted for within the original CoI framework.

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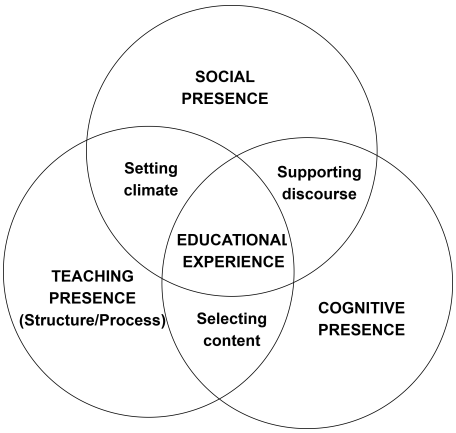


Fig. 1. Community of Inquiry Presences [11]

2.4 Generative Artificial Intelligence in Learning Environments

The rapid emergence of GenAI has introduced new dynamics into digitally mediated learning environments [1]. GenAI tools are increasingly used by students to support academic tasks such as idea generation, drafting, summarisation, and argument construction [9]. These tools can provide immediate feedback, suggest alternative perspectives, and assist in structuring arguments, thereby influencing cognitive processes associated with learning [18]. From a pedagogical perspective, GenAI has the potential to augment teaching functions by providing guidance and support traditionally associated with e-moderators, such as feedback and scaffolding [1, 19]. However, the integration of GenAI also raises concerns about over-reliance, reduced critical engagement, and the potential decline of collaborative learning practices [18].

Existing theoretical frameworks, including the CoI, do not explicitly account for the role of AI-mediated interactions in shaping learning experiences. As such, there is a need to reconsider how concepts such as presence are understood in environments where learners interact not only with peers and e-moderators, but also with intelligent systems. This study therefore first examines the configuration of the core presences within an ODeL context as a baseline for considering how AI-mediated interactions may be conceptualised within the CoI framework.

2.5 Towards a reconceptualisation of Presence

Given the changing nature of learning environments, there is a growing need to extend existing theoretical frameworks to account for new forms of interaction. In this paper, GenAI is not examined empirically, but is conceptualised as a form of *quasi-presence* that may mediate learning interactions. This quasi-presence is understood to augment cognitive processes and redistribute elements of teaching

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presence, without fulfilling the social and relational characteristics required to constitute a full presence within the CoI framework.

The extension of the CoI framework through additional forms of presence is not unprecedented. Prior studies have introduced concepts such as learning presence to account for self-regulated learning processes [10], while more recent work has proposed *self-presence*, emphasising the role of students' identity, digital embodiment, and self-efficacy in shaping online learning experiences [4]. These extensions highlight the evolving nature of presence, suggesting that it encompasses not only interaction with others, but also students' relationship with the self and the learning environment.

Building on these developments, this study introduces the notion of *quasi-presence* as a conceptual extension to account for AI-mediated contributions to learning, particularly in relation to interactions between learners and intelligent systems. This provides a basis for reinterpreting the role of presence in ODeL environments, especially with regard to the development of higher-order thinking skills. In this regard, the empirical findings of the study serve as a baseline for considering how the introduction of AI-mediated support may influence the configuration of teaching, social, and cognitive presence in ODeL contexts.

3 Methodology

3.1 Research Design

This study adopted a sequential explanatory mixed-methods design to investigate graduate students' educational experiences in an ODeL context. The research design combined quantitative and qualitative data to provide a comprehensive understanding of how teaching, social and cognitive presence contribute to the learning experience within a CSCL environment [5].

The quantitative component examined the relationships between the three presences as defined in the CoI framework, while the qualitative component explored students' perceptions of their educational experiences. This combination enabled both the identification of patterns and the interpretation of those patterns within the context of HOTS development.

3.2 Participants and Context

The study was conducted within a graduate-level course in an ODeL environment. Participants included students registered for the course, from which two datasets were obtained. The quantitative dataset consisted of responses from $N = 82$ students who completed a CoI survey. The qualitative dataset comprised two focus group discussions involving 12 students enrolled in the course, where participation was voluntary.

The course was facilitated through a CSCL environment, where students engaged in structured learning activities, discussions, and formative assessments designed to support the development of HOTS.

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3.3 Data Collection

Data were collected using two primary methods:

Quantitative data: The CoI survey instrument [20] was used to measure students' perceptions of teaching presence, social presence and cognitive presence. The instrument consists of 34 validated Likert-scale items rated on a five-point scale ranging from strongly disagree (1) to strongly agree (5), and has been widely applied in online and blended learning research to evaluate educational experiences across the three presences. It includes items categorised under teaching presence (design, facilitation, and direction), social presence (affective expression, open communication, and group cohesion), and cognitive presence (triggering event, exploration, integration, and resolution) [6]. The survey was administered electronically to students enrolled in the module. The reliability and validity of the instrument have been established in prior studies to explain educational experiences in computer-mediated and online learning environments - making it suitable for examining learning experiences in ODeL contexts [21].

Qualitative data: Online semi-structured focus group discussions were conducted to explore students' educational experiences in relation to HOTS development. The discussions were guided by a central question focusing on the extent to which the CSCL environment supported the development of HOTS, with follow-up questions aligned to the core categories of the presences. Semi-structured focus group discussions were deemed appropriate for this study as they enable the exploration of participants' experiences, perceptions, and interactions in a collaborative setting, thereby generating rich qualitative insights into learning processes and engagement [1].

3.4 Data Analysis

Quantitative data were analysed using statistical techniques to examine the relationships between the three presences. A Pearson product-moment correlation coefficient was calculated to determine the strength and direction of associations between teaching presence, social presence, and cognitive presence. In addition, multiple linear regression analysis was conducted to evaluate the extent to which teaching presence and social presence predicted cognitive presence.

Qualitative data from the focus group discussions were analysed using thematic analysis, following a contextualist approach [22, 23]. The analysis followed Braun and Clarke's six-phase process of familiarisation with the data, initial coding, theme generation, theme review, theme definition and naming, and reporting [22, 23]. The data were transcribed and coded, with themes identified based on their relevance to the research question and their alignment with the categories of teaching, social, and cognitive presence. This approach enabled the identification of patterns in students' experiences while acknowledging the interpretive role of the researcher.

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3.5 Ethical Considerations

Participation in the study was voluntary, and students were informed of the purpose of the research. Informed consent was obtained from all participants, and confidentiality was maintained throughout the study. Data were anonymised to ensure that individual participants could not be identified. Ethical clearance was obtained from the university. The study was conducted in accordance with institutional guidelines under ethical clearance numbers ERC Reference : CSET/SOC/012 and RPSC_043.

4 Findings

This section addresses the first research question by examining the extent to which teaching, social and cognitive presence function as a balanced framework in the ODeL context.

4.1 Quantitative Findings

A Pearson product-moment correlation coefficient was calculated to examine the relationships between teaching presence, social presence and cognitive presence. The results indicated statistically significant relationships between all three presences ($\rho < 0.05$).

A moderate positive correlation was found between teaching presence and cognitive presence ($r = 0.580$), indicating that higher levels of perceived teaching presence are associated with higher levels of cognitive engagement. In contrast, a weak-to-moderate positive relationship was observed between social presence and cognitive presence ($r = 0.330$), suggesting a more limited role of social interaction in supporting cognitive processes in this context.

To further examine these relationships, a multiple linear regression analysis was conducted with cognitive presence as the dependent variable, and teaching presence and social presence as independent variables. The results indicated that teaching presence significantly predicted cognitive presence, while social presence did not make a statistically significant contribution to the model.

These findings suggest that, within this ODeL context, teaching presence plays more of a central role in supporting cognitive engagement as to social presence tgat appears to have a more limited influence.

The relationships between the three presences are summarised in Table 1, while the regression results are presented in Table 2.

4.2 Qualitative Findings

The qualitative analysis of the focus group discussions provided further insight into students' educational experiences. Three dominant themes emerged, corresponding broadly to teaching presence, cognitive presence, and social presence.

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Table 1. Correlation between teaching, social, and cognitive presence

	Teaching Presence	Social Presence	Cognitive Presence
Teaching Presence	1.000		0.580*
Social Presence		1.000	0.330*
Cognitive Presence	0.580*	0.330*	1.000

* Correlation is significant at the 0.05 level

Table 2. Multiple regression analysis predicting cognitive presence

Predictor	Relationship with Cognitive Presence	Significance
Teaching Presence	Positive	Significant
Social Presence	Weak	Not significant

Teaching Presence: Structure, Guidance, and Feedback: Students consistently emphasised the importance of a well-structured learning environment, clear guidance, and ongoing feedback. The design and organisation of the course were identified as key factors supporting their engagement and progression.

Participants highlighted the value of scaffolded learning, where tasks were structured progressively, enabling them to build their understanding over time. One participant noted that the step-by-step structure of the course allowed them to track their progress and develop confidence in their work.

Constructive feedback from the e-moderator [5] was also identified as critical in supporting learning. Students indicated that feedback helped them identify strengths and weaknesses in their arguments, contributing to their development of HOTS.

Cognitive Presence: Development and Application of HOTS: Students reported increased confidence in articulating and structuring their arguments. The learning activities supported the development of higher-order cognitive skills, including reasoning and argumentation, thereby enabling students to justify their claims and consider alternative perspectives.

Importantly, participants indicated that they were able to transfer these skills beyond the course context. Examples included applying structured reasoning in workplace tasks and other academic modules. This reflects higher levels of cognitive presence, particularly in the integration and resolution phases, where learners apply newly acquired knowledge in practical contexts.

Social Presence: Limited Peer Interaction: In contrast to teaching and cognitive presence, social presence was less prominent in students' experiences. While structured group discussions facilitated interaction, there was limited evidence of sustained peer engagement beyond these sessions.

Participants indicated that they did not actively engage in informal or independent group collaboration outside of scheduled activities. This suggests that

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social presence, while present, did not play a central role in supporting their learning experience.

4.3 Summary of Findings

Across both quantitative and qualitative data, a consistent pattern emerged. Teaching presence was identified as a dominant factor in shaping the educational experience and was moderately associated with cognitive presence. Cognitive presence was evident in students' development and application of HOTS. In contrast, social presence was less influential and did not significantly contribute to cognitive engagement.

These findings challenge the assumption of a balanced interplay between the three presences in the CoI framework, particularly within structured ODeL environments. Furthermore, these findings suggest that the role and relative importance of CoI presences may be context-dependent, rather than inherently balanced across learning environments.

It is important to note that these findings emerged in a learning environment where GenAI was not formally integrated into the instructional design. This was a deliberate design choice, as the study first sought to establish a baseline understanding of how teaching, social and cognitive presence function within an ODeL context. As such, the observed dominance of teaching presence and the limited role of social presence provide a baseline for understanding how the introduction of AI-mediated support may further influence the distribution and enactment of presence in ODeL environments.

5 Discussion

It is important to emphasise that the role of GenAI is considered here conceptually, building on the baseline established in the empirical findings. This section addresses the second research question by considering how presence may be reconceptualised in the context of GenAI. The findings of this study provide important insights into the role and distribution of teaching, social and cognitive presence in an ODeL environment. Across both quantitative and qualitative analyses, teaching presence emerged as the dominant factor influencing the educational experience, with a moderate relationship observed between teaching presence and cognitive presence. In contrast, social presence was found to play a more limited role and did not significantly predict cognitive presence.

The convergence of the quantitative and qualitative findings strengthens this interpretation. Quantitatively, teaching presence appears to play the most influential role in structuring and sustaining learning, while social presence did not significantly contribute to the regression model. Qualitatively, students consistently emphasised the importance of instructional structure, guidance, and feedback in supporting their learning, while reporting comparatively limited peer interaction. Together, these findings suggest that the development of HOTS in this ODeL context was more strongly associated with instructional support than with social engagement.

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5.1 Reconsidering the Balance of Presence in ODeL

These findings suggest that the balance of presences within the CoI framework may be context-dependent rather than inherently uniform across learning environments. While the framework conceptualises teaching, social and cognitive presence as interacting in a mutually reinforcing manner, the results of this study indicate a more disproportionate configuration within the examined ODeL context. Teaching presence emerges as the primary driver in structuring and sustaining learning, with cognitive presence largely supported through this structured guidance. In contrast, social presence, although present, appears to play a less prominent role in contributing to meaningful learning in this setting.

This imbalance may be attributed to the structured nature of ODeL environments, where students rely more heavily on instructional design, facilitation, and feedback to navigate complex learning tasks. In such contexts, the intersection between teaching and cognitive presence becomes particularly significant, as the regulation of learning through structured activities and feedback supports the development of higher-order skills, such as argumentation.

5.2 Intersections of Presence and Learning Processes

The findings also highlight the importance of the intersections between presences. The statistically significant positive relationship between teaching presence and cognitive presence suggests that the processes associated with *selecting content* and regulating learning are central to students' educational experiences. These processes enable students to engage in deeper levels of inquiry, progressing towards integration and resolution.

In contrast, the limited role of social presence suggests that the intersection associated with *supporting discourse* may not be fully realised in structured ODeL environments. While opportunities for interaction were provided, sustained peer engagement beyond formal activities was limited. Similarly, the role of *setting climate* appeared to be mediated primarily through the e-moderator rather than through peer-to-peer interaction.

5.3 Implications for Generative AI as a Quasi-Presence

Importantly, these findings emerged in a context where GenAI was not formally integrated into the learning environment. As such, they provide a baseline for considering how AI-mediated tools may influence the distribution and enactment of presence in ODeL contexts. The observed dominance of teaching presence is particularly relevant when considering the potential role of GenAI, as many contemporary AI tools perform functions that overlap with instructional guidance, feedback, and cognitive support. Consequently, the findings provide a useful baseline for exploring how AI-mediated interactions may influence the enactment of presence within ODeL environments.

Given the moderate relationship between teaching presence and cognitive presence, the introduction of GenAI has the potential to augment aspects of

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both [24]. GenAI tools can provide immediate feedback, suggest alternative perspectives, and support the structuring of arguments, thereby contributing to cognitive processes traditionally associated with cognitive presence [8] . This is supported by recent research demonstrating that the integration of GenAI, when combined with structured scaffolding and prompt design, can significantly enhance students' problem-solving, critical thinking, and creativity [1, 26]. In addition, such approaches have been shown to improve students' understanding of foundational concepts, while highlighting the importance of guided use to prevent overreliance on AI-generated outputs [1].

The findings also suggest that the introduction of GenAI is unlikely to address the limited role of social presence in supporting the development of HOTS within ODeL environments. As peer interaction was not a dominant factor in supporting learning, the addition of AI-mediated support may further reduce reliance on social engagement rather than strengthening it. These observations align with emerging evidence that the effectiveness of GenAI is closely tied to structured scaffolding and instructional design, rather than social interaction. This further supports the conceptualisation of GenAI as a form of *quasi-presence*, as its effectiveness is closely linked to instructional guidance and cognitive support, rather than functioning as an independent or socially embedded presence within the learning environment.

In this context, GenAI can be conceptualised as a form of *quasi-presence*. This GenAI quasi-presence is not proposed as a replacement for the established CoI presences, but rather as a preliminary conceptual lens for understanding AI-mediated interactions within digitally mediated learning environments. Unlike traditional educational technologies, GenAI systems are capable of generating contextually relevant responses, providing feedback, and supporting cognitive engagement in ways that resemble aspects of instructional interaction. However, these interactions occur without human intentionality, embodiment, or authentic social reciprocity. In this sense, the GenAI quasi-presence may be understood as non-human, interactionally responsive, cognitively participatory, and pedagogically influential, while remaining distinct from human forms of presence.

The conceptualisation of GenAI as quasi-presence also reinforces the importance of maintaining human agency within AI-mediated learning environments. While GenAI may support cognitive engagement through feedback, scaffolding, and the generation of alternative perspectives, responsibility for critical evaluation, ethical judgement, and knowledge construction ultimately remains with the learner and educator [18]. In this sense, GenAI is best understood not as a substitute for human participation, but as a reflective collaborator that may support higher-order cognitive processes while remaining subject to human oversight and pedagogical direction [25].

The intention is therefore not to propose a formal extension to the CoI framework at this stage, but rather to open a discussion regarding whether emerging forms of AI-mediated interaction warrant additional conceptual consideration within future iterations of CoI-informed research.

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5.4 Towards a Reconceptualisation of Presence

The findings of this study suggest that presence in ODeL environments may be better understood as context-dependent and dynamically distributed, rather than inherently balanced. The integration of GenAI further reinforces the need to reconsider how presence is conceptualised, as traditional boundaries between teaching and cognitive functions become increasingly blurred.

This study therefore proposes a reconceptualisation of presence in ODeL environments, where teaching presence becomes distributed across human and technological actors, cognitive presence is augmented through AI-mediated support, and social presence remains contingent on the design of learning interactions. This perspective extends the CoI framework by introducing the notion of quasi-presence as a means of accounting for AI-mediated contributions to the learning experience.

This reconceptualisation provides a foundation for understanding learning in increasingly AI-mediated environments, where the nature of interaction, guidance, and knowledge construction continues to evolve. The reconceptualisation of presence in ODeL environments, incorporating the study's findings and the notion of quasi-presence, is illustrated in Fig. 2.

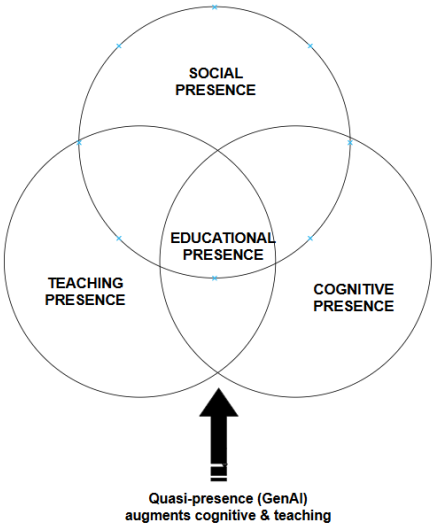


Fig. 2. Proposed conceptualisation of the CoI framework incorporating GenAI as a quasi-presence

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6 Conclusion

This study examined graduate students' educational experiences of HOTS development in an ODeL environment through the lens of the CoI framework. By combining quantitative and qualitative analyses, the study provides insight into the relative contributions of teaching, social and cognitive presence in supporting meaningful learning.

In response to the first research question, the findings indicate that teaching, social and cognitive presence do not function as a balanced framework within the examined ODeL context. Instead, a more asymmetrical configuration was observed, with teaching presence playing a dominant role in supporting cognitive engagement, while social presence contributed less significantly. These findings highlight that the development of higher-order thinking skills is closely associated with cognitive presence, which in this context is strongly shaped by teaching presence rather than social interaction. The findings therefore challenge the assumption of a balanced interplay between the three presences within the CoI framework, particularly in structured ODeL contexts.

In addressing the second research question, the study argues that the integration of GenAI has the potential to further reshape the distribution of presence. The concept of *quasi-presence* is thus proposed to describe the role of AI-mediated support in augmenting cognitive processes and redistributing elements of teaching presence, without fulfilling the relational characteristics associated with social presence. In this way, quasi-presence can be understood as a mechanism through which higher-order thinking skills may be supported in AI-mediated ODeL environments. This perspective extends the CoI framework by offering a more nuanced understanding of presence in digitally mediated learning environments.

This study has several limitations. It was conducted within a single ODeL course and relied on self-reported perceptions rather than direct measures of learning behaviour. In addition, the qualitative findings are based on a limited number of participants. GenAI was not integrated into the learning environment; instead, the study established a baseline understanding of CoI presences in the absence of AI-mediated support. Future research should examine how quasi-presence manifests within AI-mediated learning environments.

The contribution of this paper is twofold. First, it provides empirical evidence that highlights the context-dependent nature of presence in ODeL environments. Second, it introduces the concept of quasi-presence as a theoretical extension to account for the influence of AI-mediated interactions on teaching and learning processes.

Future research should explore the integration of GenAI within CSCL environments to examine how quasi-presence manifests in practice, particularly in relation to its impact on cognitive engagement and the potential implications for social interaction. Further investigation is also required to determine how learning environments can be designed to balance the benefits of AI-mediated support with the need to sustain meaningful human interaction.

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In conclusion, as ODeL environments continue to evolve, there is a need to reconsider established theoretical frameworks to account for emerging forms of interaction. The reconceptualisation of presence proposed in this study provides a foundation for understanding learning in increasingly AI-mediated contexts, where the boundaries between teaching, cognitive, and technological support are progressively blurred.

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A Comparative Case Study of Undergraduate Software Engineering Modules in Germany and South Africa

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Abstract. Designing industry-relevant Software Engineering (SE) curricula is challenging, as it requires selecting appropriate module content and effective teaching methods. Content selection is difficult because SE content should be industry-relevant, yet teaching methods can vary widely across lecturers and institutions. Lecturers often lack guidance on how their modules compare to others. Reviewing content and teaching methods at other universities can help improve them. This paper presents a comparative case analysis of two cases of SE-related modules from universities in South Africa and Germany. A framework for comparing SE modules using the IEEE Software Engineering Body of Knowledge (SWEBOK) and Bloom's Taxonomy is presented and used in the analysis. The findings highlighted gaps in SE knowledge coverage across the modules and differences in the cognitive levels targeted by the teaching methods. The results also provided insights into teaching methods for key SWEBOK knowledge areas. The study also verifies the framework's value in enabling a structured comparison of modules and guiding academics toward potential areas for improvement to strengthen SE graduate competencies that better align with industry needs.

Keywords: Software Engineering Education · Curriculum Development · Computer Science Education, SWEBOK

1 Introduction

Software has become pervasive in modern society, and developing large-scale systems requires many software engineering (SE) professionals [8]. SE provides systematic methods and tools for developing complex software systems [12] across the full software development life cycle (SDLC) [23]. However, there is an industry skills gap for SE graduates [2], who often lack the necessary skills and knowledge for a career in the software industry [1]. International bodies such as

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the ACM and IEEE have provided model curricula and guidelines for undergraduate SE-related programs. For example, [12] provides a consensus on the content of teaching aimed directly at SE. More broadly, the CC2020 IEEE project provides a comprehensive, competency-focused framework that links computing learning objectives with the skills and knowledge required to design modern, industry-aligned curricula for Computing disciplines, including Information Systems (IS), Computer Science, SE, IT and computer engineering [9]. The IS2020 model [13,22,14] outlines the required competencies for graduates of IS programs, which include those related to the SDLC, indicating some relevance to SE-related modules.

For this paper, we use the following definition of terms relevant to SE teaching, provided by the IS2020 [13]: A *program* is an undergraduate or graduate degree pathway (e.g., BSc) that specifies the competencies graduates must demonstrate. A *module* (or course) is a curriculum unit taught in a specific semester, defined by a *course description*. Each module specifies *learning outcomes* — what students must know and be able to do — and these are supported by more granular learning objectives. *Teaching methods* are chosen by the lecturer to help students achieve the intended outcomes [4]. The adoption of new teaching methods in the classroom has a high impact on the students' learning experiences [18]. Traditional teaching methods involve the presentation of lectures, and in some cases practical exercises [5], whilst newer methods can include gamification and simulations, amongst others.

Whilst there is a fairly common understanding of SE content and a vast amount of learning material available, the choices can be overwhelming to lecturers. As a result, the topics and teaching methods can vary widely in practice. Many lecturers are motivated to improve their content and teaching methods to better support students' learning. However, due to their high workloads and limited available time for pedagogical training, guidance on comparing their modules with others would be beneficial in helping them identify opportunities for improvement.

Another demand on lecturers when designing an entire SE curriculum, or individual courses and modules, is to align SE skills with industry requirements [7,2]. To bridge this gap, a standardised hierarchical framework, the Software Engineering Body of Knowledge (SWEBOK), was developed by the IEEE [23]. It defines the scope of knowledge for SE, and a foundation for SE curriculum design [6]. It covers 18 key *Knowledge Areas* (KAs) in SE related to the SDLC, such as software requirements, design, construction, software quality and testing. The KAs are divided into *sub-KAs*, which are further detailed by *Knowledge Items* (KIs). For example, KA *11. Software Engineering Models and Methods*, is further refined into, amongst others, sub-KA *11.4. Software Engineering Methods* and KI *11.4.4. Agile Methods*.

In higher education, one of the most widely used international hierarchical frameworks for categorising educational objectives is Bloom's Taxonomy, revised by Krathwohl et al. [11]. It is often used to classify learning objectives for modules and to guide teaching methods and assessments. Whilst several studies and

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international standards can partially guide academics in designing SE curricula and teaching methods, little work has been conducted on approaches or frameworks to compare individual modules within SE curricula. Studies that compare SE modules in South Africa with those in a European country are also limited. The purpose of this paper is to provide a comparative analysis of SE modules using a systematic framework and a case study strategy. The case focused on undergraduate SE modules offered by two universities: Nelson Mandela University (NMU) in South Africa and Reutlingen University (HSRT) in Germany. The primary research question (RQ) is: *How do two SE modules at HRST and NMU compare in learning objectives, content and teaching methods?*

The contribution of this paper is twofold: (i) A theoretically-grounded framework that guides the comparison of teaching SE modules based on the SWEBOK to document the content taught and the methods used, and an analysis of the learning objectives according to Bloom's taxonomy. (ii) The application of the framework to the comparison of two case modules, which highlighted potential areas of improvement to the modules. The findings can provide lecturers and researchers with guidance on analysing and comparing SE modules with those of other universities to improve their teaching and, ultimately, the quality of SE graduates.

This paper is structured as follows. Section 2 reviews related work that can inform SE curricula. Section 3 presents the research design, including the theoretical framework. Section 4 presents the application of the framework to the cases, including the results of the data collection and analysis. Section 5 provides a discussion of the findings and the threats to validity. Section 6 concludes the paper and proposes future work.

2 Related Work

The literature review used the IEEE and Google Scholar libraries, and was organised into two categories: (i) articles from an educational perspective; and (ii) articles in education which used SWEBOK, thus having a more professional perspective. Articles in category (i) were identified using the two libraries, yielding 332 citations. For category (ii), the search started on the IEEE SWEBOK website[3], and 109 publications were found that discussed the SWEBOK guide. The articles found in both categories were then further refined and screened according to the following criteria: (i) written in English, (ii) the title addresses SE university education, (iii) published after 2010. Snowballing from relevant works was then applied.

2.1 Teaching Approaches and Methods in SE Education

When designing SE curricula, it is important to incorporate a variety of learning resources and media to support different learning styles and enhance student engagement. These resources may include traditional materials such as textbooks,

[3] https://www.computer.org/education/bodies-of-knowledge/software-engineering

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as well as digital and interactive media such as emails, images, videos, websites, and social media platforms, which can facilitate communication, collaboration, and knowledge sharing among students [1].

It is crucial that SE education include not only theoretical lectures but also a practical, hands-on approach (learning by doing) that applies SE principles through practical exercises and project work [16,17]. However, designing these practical activities is challenging because they are complex to set up, take considerable time and effort, and are difficult to keep students engaged [8,18]. In a research landscape article in SE education [8], it was reported that common challenges in SE teaching include choosing suitable teaching methods and tools, as well as the gap between teaching costs and learning outcomes. Their study reviewed Systematic Literature Reviews (SLR) articles from 2004 to 2019 and found that existing SLRs of SE education have a limited focus and do not provide an overall overview of the state of the art in the field. Their review identified that a common teaching approach for SE education was Problem-based Learning (PBL), which aligns with the learning-by-doing approach. In PBL, learning begins with a problem, and students acquire knowledge and skills by working to solve it. One PBL method is to use maintenance tasks, in which students correct software developed by others [17].

The most popular teaching methods for SE identified from the review of selected SLR papers in [8] were simulation and games. Simulations are models that express real-world systems or scenarios. Two popular simulations are game-based learning and gamification. Game-based learning is learning through the development of games, whilst gamification employs game design techniques and elements in a non-game context. These methods are primarily used to improve student engagement.

Feedback on teaching methods and student engagement was collected from lecturers and experts using questionnaires in the study of [18], who confirmed that PBL is a common teaching approach. The authors also noted that the flipped classroom, which promotes active engagement through student-prepared materials and guided discussions, is a popular approach. The common teaching methods they identified were gamification and role-playing. Their paper proposes a framework for mapping courses/modules related to the SE aspects in the SDLC to teaching methods.

Case studies are used as a teaching method in SE education to provide a realistic real-world context in which students can see how concepts are applied in practice [17,16]. Teamwork with rotating roles and assigned tasks is another effective teaching method used in SE undergraduate modules [1]. Other teaching methods reported in [1] include periodic workshops, consulting services for lecturers and students, and collaboration with experts and industry professionals. This collaboration can prepare students for industry software development. In the study [16], they propose an SE undergraduate curriculum that emphasises a real-world case-study-based software development project, in which students learn coding fundamentals and the technical skills required by industry. They incorporate coding, software quality, and metrics in the first year, following real-

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world specifications. Their teaching methods include weekly hands-on practicals with feedback from experienced software engineers, and presentations from industry partners.

2.2 Works that Build on SWEBOK

The Software Engineering Education Knowledge (SEEK) framework [4] provides curriculum guidelines for undergraduate degree programs in SE [15,12]. These guidelines build on SWEBOK for structuring and completeness, thus providing an accepted standard for the outline of modules for an SE program. SEEK and SWEBOK are both SE frameworks, but whilst SEEK's main audience is academics, SWEBOK focuses on providing guidance on what professional software engineers should know. SWEBOK is more comprehensive than SEEK.

A survey of SE practitioners, mostly from Turkey, was conducted in [7] to address knowledge gaps between SE education and industry needs. The study adopted a SWEBOK V3-based approach using 12 SWEBOK KAs, omitting the foundational KAs. They highlighted the usefulness of KAs and sub-KAs to obtain the findings showing that SE curricula gaps exist in software maintenance, configuration management, and testing. Dolog, Thomsen, and Thomsen [5] described a methodology to assess PBL in an SE curriculum at a University in Denmark by documenting the main learning objectives of modules, such as *Internet Technologies*, or *SE Management*, and compared them in two dimensions: (i) the Graduate SE 2009 Curriculum Guidelines (GSwE2009) [19], where core concepts and expected learning outcomes of SE graduates are defined, and (ii) the mapping of skills for SE graduates according to [3], who mapped the SWEBOK concepts to Bloom's taxonomy for three software engineer profiles (experience levels of novice, four years' experience, and highly skilled engineer). The authors then assigned to each SWEBOK KI the knowledge levels of Bloom's taxonomy from the SWEBOK curriculum guidelines and the GSwE2009. With this overview, the coverage of skills across the curricula could be visualised at the semester level. However, they did not provide an approach to compare the content of individual SE modules.

Alarifi et al. [2] proposed a structured approach for improving SE curricula that better meets industry needs. The approach incorporated SWEBOK and the SE Curricula Development and Evaluation Process (SECDEP), which focuses on professional competency development and career progression for software engineers. Their study collected information on curricula, courses and their expected outcomes from faculty members and students at several Saudi universities. SECDEP and the SWEBOK KAs were used to analyse the collected data and to evaluate the curricula. Their findings emphasise that the comprehensiveness of SWEBOK KAs can be used to identify uncovered topics and adjust their curricula accordingly.

An approach to monitor and evaluate undergraduate curricula against a standard body of knowledge was proposed by Qamar and Ikram [20]. Their approach

[4] `http://sites.computer.org/ccse/`

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used a concept map of Software Requirements Engineering based on the KAs of SWEBOK and applied it to three universities in Pakistan. They identified gaps (missing concepts), hierarchical misalignments, and conceptual misconceptions in the undergraduate SRE courses they examined. The inferred knowledge supports more effective curriculum monitoring and evaluation, enabling targeted curriculum improvement and better alignment with professional standards. However, the case studies were all from a single country and did not address the learning objectives or teaching methods. Only the KAs of SWEBOK were analysed, not the KIs.

In summary, none of these studies used SWEBOK as a structure for self-assessment and comparison of modules, in which KAs and KIs are classified according to learning objectives and methods using Bloom's taxonomy.

3 Research Design

3.1 Case Study Strategy

Because the primary RQ requires comparing two SE-related modules, the case study strategy of Runeson and Höst [21] was adopted, as their guidelines provide a structured process for conducting SE case studies in real-world contexts. Recommended practices for this strategy include clearly defining objectives, RQs, and units of analysis; using multiple sources of evidence; following consistent data collection procedures; maintaining a traceable chain of evidence; validating findings with participants; and applying systematic analysis techniques. The study should be reported in sufficient detail to support replication and generalisation, thereby improving the overall quality and trustworthiness of the research.

3.2 Research Objective and Questions

This study forms part of a broader collaboration between Nelson Mandela University (NMU) and Reutlingen University (HSRT) on Computer Science and Software Engineering curricula. In 2023, the Departments of Computing Sciences and Informatics initiated joint activities, including student exchanges, to strengthen internationalisation. As part of this collaboration, a comparative analysis of their Computer Science and SE curricula was launched, and this paper reports on the project's first phase. The high-level objective of this study is to compare two SE-related modules offered at these universities, which have been long-standing international partners since 2006. The subsidiary RQs are:

RQ1: Which framework can support a systematic comparison of two SE modules?
RQ2: What learning objectives and knowledge content are included in each module at HSRT and NMU?
RQ3: How do the modules compare with respect to their teaching methods?

Lecturers of the module were the 1st and 3rd authors of this study. The application of the framework presupposes that there are fundamental similarities in the module metadata, and therefore, additional modules were not compared in this phase.

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3.3 Units of Analysis

The units of analysis were the modules that are related to IS development tasks that apply SE techniques, as shown in Table 1.

Table 1. The selected SE modules as Units of analysis.

Institution	Module	Module name	Year/Semest.	Effort
NMU	WRIV201	Information Systems 2.1	2nd yr. 1st sem.	60 hrs
NMU	WRIV202	Information Systems 2.2	2nd yr. 2nd sem.	60 hrs
HSRT	SWT1	Software Engineering 1	3rd sem.	150 hrs

The first module was *Software Engineering 1* (SWT1), presented in HSRT's Informatics degree. The second module was *Information Systems 2* (WRIV20x), presented in the Computing Sciences degree at NMU, which spans over two semesters (WRIV201 and WRIV202) [5], and contributes 6 NMU credits on successful completion for each semester. We refer to this module as WRIV20x. The module aims to equip students with the knowledge and skills to analyse, define, and model a company's requirements and to expose students to Computer-Aided Software Engineering (CASE) tools. To pass each semester module, a final mark of 50% must be achieved, comprising a class mark of 40% and an examination mark of 60%. The class mark consists of a Portfolio of Evidence (PoE) of 50% and a formal assessment mark (comprising two tests) of 50%. The PoE includes the mini-project mark and class activities.

In the *Media and Communication Informatics* (MKI) program at HSRT, the SE learning area comprises two 5 ECTS modules [6][7]: *Software Engineering 1* (SWT1) and *SE2*. SWT1, offered in the third semester, introduces fundamental SE concepts for developing large ISs, including eliciting and documenting user requirements, relating requirements to quality management and development processes, and applying basic SE methods and project management techniques. Assessment consists of a two-hour written exam and a case study project.

3.4 Theoretical Framework and Sources of Evidence

This section describes the framework for comparing SE modules and addresses RQ1. The proposed framework, derived from the literature review and illustrated in Fig 1, consists of six activities, Act1-Act6, and systematic analysis techniques as specified as a recommended practice in the case study strategy of [21], discussed in Section 3.1. The six activities are classified into three phases: data collection (Act1 and Act2), data analysis (Act3, Act4 and Act5) and then reflection.

Act1: Assess relevance and application of SWEBOK KIs in module adapts the approach of Alarifi et al. [2]. Each of the 363 SWEBOK KIs is assigned a numeric score for each module. The module's primary lecturer and other experts rate two aspects: the

[5] NMU module browser

[6] MKI module handbook.

[7] Following scheme can be used to compare international credits: 8 NMU credits=2 USA credits=4 ECTS; 1 ECTS=30 hours, 1 NMU=10 hours.

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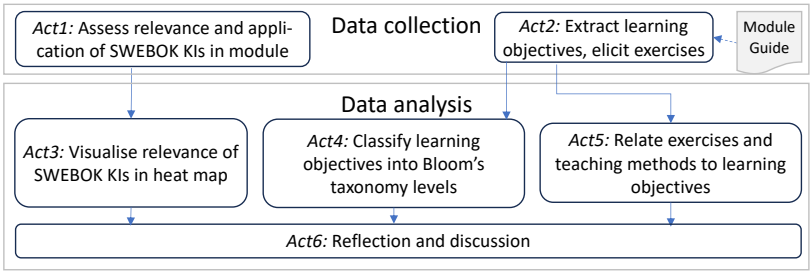


Fig. 1. A framework for comparing SE modules using SWEBOK and Bloom's

KI's relevance to the module and the extent to which it is applied. Relevance is rated on a 4-point Likert scale: 0 – not in scope, 1 – brief discussion, 2 – in-depth discussion, 3 – main topic. Application, reflecting the use of exercises or case studies, is rated on a 3-point scale: 0 – no application, 1 – small exercise, 2 – in-depth exercise. All ratings are recorded in a spreadsheet, provided as additional research data with the structure `ID`, `SWEBOK KA`, `sub-KA`, `KI`, `Chapter`, `Relevance`, `Application`.

Act2: Extract learning objectives, elicit exercises, includes the extraction of the modules' learning objectives from the module guide and the tabulation of these. The work [18] was used as the theoretical foundation for this activity. Then the teaching methods associated with each SWEBOK KI are elicited from lecturers, and, additionally, the exercises used and their implementation type - whether conducted at the class, group, or individual level.

Act3: Visualise relevance of SWEBOK KIs in heat map is used to analyse the similarity of two modules by comparing the *relevance* of all KIs, following the work of [7]. For the comparison, the coverage *c* of a SWEBOK KA in a module is calculated by the sum of each KI assessed in *Act1*, calculated as:

$$c_{module_m} = \sum_{ki=0}^{N} relevance_{KI}$$

where KI is the SWEBOK KI and N is the number of KIs per KA. Then, the similarity of the two modules is calculated based on their absolute difference in *relevance* of each of the 18 SWEBOK KAs $similarity_{KA} = abs(c_{module_1} - c_{module_2})$, where KA is the SWEBOK KA, and c is the summarised *relevance* of the KIs in each module. Modules were considered more similar when a larger number of KIs were discussed in depth or treated as main topics. To visualise these similarities and differences, a heat map based on $similarity_{KA}$ can be created in Excel using conditional formatting. This heat map shows which SWEBOK KIs are covered in both modules and highlights topics included in one module but missing in the other. Because the large number of KIs would make the heat map difficult to interpret, the visualisation is aggregated to the KA level, as described above.

Act4: Classify learning objectives into Bloom's taxonomy levels, maps the learning objectives from *Act2* to one of Bloom's six cognitive levels using the revised CC2020 verb list [9]: *Remember* basic facts, *Understand* concepts and relations, *Apply* techniques in new contexts, *Analyse* component relationships, *Evaluate* decisions, and *Create* original work. The classification results are then tabulated. In *Act5: Relate exercises*

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and teaching methods to learning objectives, the identified exercises are related to the learning objectives and associated teaching methods.

Act6: Reflection and discussion is an important activity for verifying results and is where stakeholders, such as lecturers or others, discuss and reflect on the documented results, particularly the identified coverage of KIs, the learning objectives, the teaching methods used, and the similarities or differences. These steps are important for understanding the lecturers' rationale for covering some SWEBOK areas whilst others are not. From this activity, suggested improvements to the modules should be made.

3.5 Data Collection Protocol

The framework in Fig 1 guided the data collection phase (Act1 and Act2), which served as a consistent data collection protocol, in line with recommended practice for the case study strategy (Section 3.1). The data included both quantitative and qualitative evidence from various sources, thereby adhering to the recommended practice for case studies. Qualitative data on the teaching methods and exercises used were collected from two sources: written details in module guides (including the learning objectives) and the lecturers' intrinsic knowledge; and the levels and related descriptions of Bloom's Taxonomy, which include quantitative and qualitative data, respectively.

A Data Capture Sheet was developed to include all SWEBOK KAs, sub-KAs, and associated KIs for *Act1*, together with the corresponding explanatory chapters from the SWEBOK Guide, compiled to provide lecturers with the necessary context for evaluating the underlying concepts. Fig 2 shows an extract of sample data of the Data Capture Sheet template. In the last row of this example, a relevance rating of 2 is assigned to *KI 4.4 Agile Methods*, since an in-depth class discussion is conducted for the module's practical component, which is assigned *2 – in-depth exercise*.

ID	SWEBOK KA	SWEBOK sub-KA	SWEBOK Knowledge Item	Fourth Level	Chapter	Relevance	Application
11.1.1	11. Software Engineering Models and Methods	1. Modeling	1.1. Modeling Principles		11-2	2	1
			...		...	...	...
		4. Software Engineering Methods	4.1. Heuristic Methods		11-7		
			...		...	...	...
			4.4. Agile Methods		11-10	2	2

Fig. 2. Excerpt of Data Capture Sheet for *Act1*: Relevance of SWEBOK KIs in SWT1.

4 Findings of Data Collection and Analysis

This section describes the results of applying the framework to the cases in an evaluation of the module conducted by the module's primary lecturers. The findings address RQ2 and RQ3.

4.1 Knowledge Content and Learning Objectives (Act1-Act2)

All collected data can be accessed on Zenodo[8]. As per the data collection protocol, *Act1's* results were recorded in the standardised Data Capture Sheet and in *Act2*, the data related to the learning objectives, teaching methods, exercises and Bloom's Taxonomy were collected.

[8] additional research data: `https://doi.org/10.5281/zenodo.13903541`

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4.2 Visualisation of SWEBOK KIs (*Act3*)

The data from *Act1* are visualised in Fig 3, which shows the similarity between the two modules based on SWEBOK KAs. The row `sum` shows the summarised relevance of each KA. A higher sum means greater module coverage of the KA. The lower the *difference*, the more closely aligned the two modules are in terms of the specific KA.

An analysis of the self-assessment data revealed that the two modules are fairly similar in terms of KAs. More specifically for 12 of the 18 KAs, the modules are either aligned or are 80 % similar(difference ≤ 7); these are: (1 2, 3, 6, 7, 8, 9, 10, 11, 13, 17, 18). However, the modules differ in Software Construction (KA 4) and Software Testing (KA 5), Software Quality (KA 12), SE Professional Practice (KA 14), SE Economics (KA 15), and Computing Foundations (KA 16). The primary lecturer confirmed that software quality assurance and testing are not learning objectives for WRIV20x and are thus neglected in the module. The difference in Software Construction is interesting. WRIV20x focuses more on the analysis and design of a software system's requirements. A brief discussion on Software Construction is done, but students are not required to implement any requirements.

Module		SWT1	WRIV20x	
KA.ID	SWEBOK KA (L1) Relevance->	SUM	SUM	Difference
1.	Software Requirements	43	38	5
2.	Software Architecture	1	0	1
3.	Software Design	16	19	3
4.	Software Construction	16	6	10
5.	Software Testing	31	8	23
6.	Software Engineering Operations	0	5	5
7.	Software Maintenance	7	2	5
8.	Software Configuration Management	5	0	5
9.	Software Engineering Management	8	2	6
10.	Software Engineering Process	9	6	3
11.	**Software Engineering Models and Methods**	**16**	12	4
12.	Software Quality	10	1	9
13.	Software Security	2	2	0
14.	Software Engineering Professional Practice	19	2	17
15.	Software Engineering Economics	10	0	10
16.	Computing Foundations	0	17	17
17.	Mathematical Foundations	0	0	0
18.	Engineering Foundations	0	0	0

Fig. 3. Visualised Relevance Similarity of SWT1 and WRIV20x SWEBOK KAs. Legend: Aligned (difference 0-3), $\sim$ 80% similar (4-7), 60% - 40% similar (8-12), and Large differences (>12).

4.3 Classification of Learning Objectives (*Act4*)

The mapping of the learning objectives of both modules, NMU's *WRIV20x* and the HSRT's module *SWT1*, to the six levels of Bloom's taxonomy showed that both modules only incorporated the first four levels of the taxonomy in the wording of their learning objectives, i.e. neither module specified Level 5 Evaluate or Level 6 Create. This result may be appropriate, since both modules are undergraduate modules. An abstracted, high-level view of the mapping results is shown in Table 2.

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Table 2. Learning objectives of SWT1 and WRIV20x by Bloom's Taxonomy.

Level	Learning Objectives WRIV20x	Learning Objectives SWT1
4 Analyse	define company's requirements for an IS; data UML models; describe UML notation and modelling concepts	requirements and project management techniques; weaknesses in requirements
3 Apply	modelling skills with a CASE tool; relational database (DB) design skills; UML class, use case, activity diagrams construction	requirements engineering to an practical example; design and development principles for ISs; software quality assurance, test driven development; modelling of ISs
2 Understand	design and implementation concepts for IS	SDLC processes, task and product complexity; ethics; project-, quality- and configuration management
1 Remember	basic HCI concepts and principles; different system development methodologies and phases; types and use of software tests	basic SE concepts and modelling principles; characteristics of traditional and agile methods and processes for large software development

In addition to the quantitative mapping, a more detailed qualitative analysis of the terms used in the learning objectives found in the module documents showed that both modules have the following in common: (i) they cover foundational concepts of SE and human-computer interaction (HCI), (ii) students apply SE techniques to a problem(PBL), (iii) students perform systems analysis and software design activities for large systems, and (iv) both focus on requirements engineering, including model-based documentation (e.g., UML diagrams) and appropriate CASE tools.

The modules differ in the following ways: (i) WRIV20x covers relational DB engineering, whereas in MKI, this is a 3rd-semester module on its own. (ii) In contrast, SWT1 has a large focus on software quality (tightly related to requirements), which is not the focus of WRIV20x. (iii) Furthermore, WRIV20x places more emphasis on UI, which is in MKI a module on its own.

4.4 Teaching Methods (*Act5*)

The analysis of teaching methods showed that both modules adopted a PBL approach with several similar teaching methods and exercises. Examples of these, as they relate to the SWEBOK KAs in the WRIV20x module, are shown in Table 3. A summary of the teaching methods is provided in Table 4. In WRIV20X, teaching is based on unit guides and content videos that students must complete before the topic is discussed in the lecture. During the lecture, specific learning objectives are enforced by using teaching methods such as *team discussions*, *exercises*, and *live quizzes* or *polls*. To make the module as practical as possible, a PBL approach with a case study is used, in which students work in teams on a mini-project that emulates the SDLC stages. The students define requirements and use cases for an IS, design the DB schema and UIs, compile software specifications, design and develop a SE solution, and implement parts of it.

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Table 3. Exercises used in WRIV20x mapped to SWEBOK KAs

SWEBOK KA	In-class	Homework / Assignment
1 Requirements	Identify stakeholders and non-functional reqs.; Review faulty UML	Create UML diagrams (use case, class, activity)
2 Design	Review faulty UML; Rate file/data structure (3) UX rating	Derive DB tables from class diagram; UI heuristic eval.
3 Construction	Team debate: group size vs. project duration	Implement two use cases
4 Test & Maint.	Quizzes	–
7 SE Mgmt.	–	Form teams of 2
8 SE Process	–	Apply Scrum / agile methods
9 SE Models	Create UML diagrams	–
11 SE Prof. Practice	Anonymous text poll + discussion; IS dev. role-play	Research SE roles; Present specific IS team role
13 Comp. Found.	Team debate	Execute SQL queries

The teaching in SWT1 consists of three building blocks: weekly lectures, worksheets, and case studies. (1) In a *weekly lecture*, SE concepts are presented using slides. With several questions and small exercises during the lecture, students try to apply the presented topics. At the start of the UML unit, students do a self-review of their own key UML diagrams using a scale from beginner to expert. This helps the lecturer focus on unfamiliar diagrams and skip known content. In a collaborative workshop, students model a large system under the lecturer's guidance and create a UML component diagram. Key design decisions i.e. structure, dependencies, interfaces are discussed through targeted questions. (2) The students complete *worksheets* with various tasks as preparation for the final assessment. The worksheets cover (i) Process models and development processes, and the ACM Code of Ethics (ii) Software metrics with various tools to perform calculations of software metrics and code quality evaluation. (iii) Black-box and white-box testing with equivalence classes and control graph exercises. (iv) Quality requirements. (3) In a *case study*, the students work in teams to

Table 4. Teaching methods used in SWT1 and WRIV20x

Teaching method	SWT1	WRIV20x
example	✓	✓
class discussion	✓	✓
discussion with neighbor	✓	✓
exercise	✓	✓
exercise with neighbor	✓	–
learning control questions	✓	✓
research	✓	–
poster	✓	–
question	✓	✓
self-rating	✓	–

compile a Software Requirements Specification (SRS) based on ISO 29148 [10]. In team meetings, the students defend their solution and receive feedback on their current SRS, which contributes 40% of the final mark.

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4.5 Reflection and Discussion(*Act6*)

The discussions held by the primary lecturer of each module highlighted the following workload differences between the two modules:

(i) Student workload differs slightly: SWT1: 150 h/semester, WRIV20x: 120 h/2 semesters.
(ii) In SWT1, students develop a full SRS as a case study; in WRIV20x, they work on separate SRS aspects.

They also confirmed the similarities of the modules as follows: (i) Learning objectives are documented similarly in both module guides. Lecturers update them when revising lectures or exams, though changes require an official process. (ii) Table 2 shows mostly similar learning objectives in the two modules. (iii) Both modules provide individual and team feedback; WRIV20x uses the e-learning system and discusses anonymous samples in class. (iv) From Fig 2, it is clear that both modules cover more than three-quarters of the SWEBOK 18 KAs. (v) The wording of the learning objectives in both modules mostly reflects the SWEBOK item at the sub-KAs level and not at a granular KI level.

Some differences were: (i) Self-rating has not yet been used in SWT1. (ii) Self-review of given UML diagrams has not yet been done in WRIV20x. (iii) SWT1 learning objectives were not worded according to Bloom's Taxonomy.

The first application of the framework, reported on in the previous sections, was conducted by the authors of this paper as a first evaluation of the modules. A second evaluation was conducted, albeit on a smaller scale, with different evaluators to provide an additional source of evidence and to limit the potential bias. In this second evaluation, the same modules were used, but only *Act1* of the framework was applied. For both modules WRIV20x and SWT1, the evaluator was an alternative lecturer of the module. The results are shown in Fig 4.

The scores from the second application of *Act1* differed from both the primary lecturer's original evaluation and the second evaluator's ratings, but they followed the same overall trend. In particular, KIs not included in SWT1 are visible in the visualisation, thereby highlighting possible gaps in the module content.

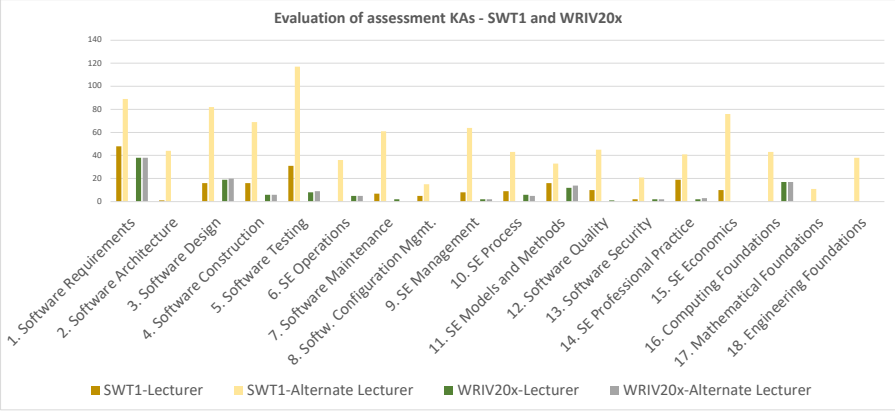


Fig. 4. Evaluation of Assessment covering the 18 KAs (SWT1 , WRIV20x).

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5 Discussion

The case study demonstrated replicability by following established case study practices, including defined objectives, research questions, a data collection protocol, units of analysis and multiple sources of evidence. All concepts, activities, and measurement items used in the presented framework was derived from existing literature, thereby ensuring theoretical grounding and supporting content and construct validity [22,20]. The successful application of the framework to a real-world case demonstrated its practical applicability and ability to identify key insights that can assist lecturers and researchers in improving SE module quality, thereby validating its usefulness.

Neither module included learning objectives above Level 4 of Bloom's Taxonomy. While this could initially be interpreted as a potential gap, it was considered appropriate given that both modules are undergraduate and typically focus on application and analysis rather than evaluation and creation. The finding also showed that the learning objectives of the two modules were largely similar; however, some were not consistently formulated according to Bloom's Taxonomy. One module lacked a self-review component for UML diagrams. These findings resulted in specific recommendations for improving the modules going forward. Both modules used a PBL approach with a case study and practical exercises as recommended by [16,17]. Teamwork and industry-involvement approaches similar to [1] were also adopted by both modules. For the evaluated modules, both the German and South African primary lecturers used similar types of exercises. There are three possible reasons for this similarity: (i) The principles of SE are the same worldwide. (ii) The teaching of SE concepts is often based on industrial projects and experiences that the lecturers gained before taking up their roles at the university. (iii) Several initiatives, such as SWEBOK, SE2014, CC2020, IS2020 and others, have guided the structuring and outline of SE programs. In that sense, efforts to standardise SE teaching have impacted individual modules and shown some evidence of success.

This study faces several threats to validity, as outlined by [21]. *Reliability* concerns the influence of the researchers and the repeatability of the study. Because two of the authors were some of the evaluators of the KAs and KIs, there is potential bias. This was mitigated by using module guides, publishing the extraction sheet for departmental feedback, and conducting a lightweight second evaluation of *Act1* by two independent evaluators familiar with the modules. A further reliability threat is the subjective interpretation of content descriptions, which was reduced through the standardised KA and KI definitions provided by SWEBOK. *Internal validity* addresses whether the collected data support sound conclusions and reduce the effect of unknown influencing factors. Using a consistent data protocol and multiple sources of evidence reduced potential threats to internal validity. *External validity* concerns the generalisability and transferability of the findings. As the study covers a single case with two modules, generalisability is limited to similar contexts. However, transferability is supported by using a theoretical framework, a data extraction sheet and publicly available standard models such as SWEBOK and Bloom's taxonomy and by describing the framework in detail. Overall, the study is credible, transferable, dependable, and confirmable within comparable contexts. The findings offer useful insights into the relevance and adoption of SWEBOK KAs and KIs, the applicability and appropriateness of learning objectives, and teaching methods in SE modules. These insights can assist lecturers and other faculty members with a deeper understanding of quality requirements in SE education.

A limitation of the study was that the framework was applied to only two modules and universities. In addition, the modules had slightly different credit weightings, which

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may have contributed to differences in the level of coverage of some knowledge areas. A limitation with the framework is that it does not account for the expertise of the module evaluators. Future work should apply the framework to additional institutions to strengthen its validity further and explore its adaptability across diverse educational contexts. Future studies should consider incorporating raters' knowledge and experience levels, potentially assigning weights based on these factors. The module credit weighting should also be considered in the equation. Future research should investigate the impact of innovative teaching methods, such as gamification, UML diagram correction, and student self-review, on students' engagement and experiences. Improving these methods can be incorporated into strategies for enhancing SE education and graduate outcomes.

6 Conclusion

This paper confirms the essential role of the two standards, the SWEBOK guide and Bloom's Taxonomy, in guiding lecturers with the design of undergraduate degree modules. Both standards were incorporated into the proposed, theoretically grounded framework for systematically comparing SE modules. The successful application of the framework to modules at universities in two different countries, South Africa and Germany, demonstrated its ability to provide structured, rigorous comparisons, reduce ambiguity in the topics covered, and align module content and learning objectives. Both case modules identified areas for future improvement. The framework offers academics a practical tool for analysing and enhancing module content and teaching methods, reducing the gap between industry and academia, and ultimately improving SE program quality and the preparedness of SE graduates to meet industry needs. In future work, the proposed framework will be applied across a broader set of courses and institutions in order to identify recurring patterns and assess its generalizability.

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From Participation to Performance: The Impact of Gamified Engagement on First-Year Programming Academic Outcomes

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Abstract. The role of active participation in learning is well established as a key determinant of successful learning outcomes. In computing education, where students are required to learn programming, traditional instructional methods often do not sufficiently promote active participation. Gamification is an innovative approach used to create more interactive learning environments for programming students. While gamification has gained considerable traction within programming education, existing research reports mixed findings regarding its effects on learning outcomes, thereby highlighting the need for further empirical investigation. This study aimed to analyse the influence of student engagement within a gamified programming learning environment on academic achievement in a first-year Internet Programming module. The design of the gamified environment incorporated several established frameworks, including the D6 framework, the HEXAD user typology, and the RAMP model, to ensure alignment between gamification elements and student motivations. Four gamified platforms were implemented, namely Khan Academy, Codecademy, Kahoot!, and Gimkit, to target different motivational drivers. Spearman's rank-order correlation was used to determine the relationship between student participation measures and academic performance. Statistically significant positive relationships were found between gamification participation and all assessment outcomes. These findings indicate that a theoretically grounded, multi-dimensional gamified learning environment is positively associated with both student engagement and academic performance in foundational programming education. This study contributes to the literature on innovative programming pedagogy by demonstrating how gamification can be used to reinforce foundational programming skills in an age of emerging technologies.

Keywords: Student Engagement; Learning Outcomes; Active Learning.

1 Introduction

"Tell me and I forget, teach me and I may remember, involve me and I learn" - Xun Kuang. [1]. This proverb highlights the importance of active participation in the learn-

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ing process. Educational research has long emphasised that students learn more effectively when they are actively engaged in learning activities rather than passively receiving information [2]. In computing education, particularly in introductory programming modules, active engagement is essential for developing the problem-solving and analytical thinking skills required to master programming fundamentals [3, 4]. However, many methods of instruction simply can't provide students the interest required to learn to code. There's a significant need to incorporate different pedagogical strategies, such as gamification, into the programming education learning environment to engage students in active participation and learning [5 - 7].

The concept of gamification can be described as the integration of game design elements (points, badges, leaderboards, quests) into non-game contexts as a means to boost motivation and increase participant behavior [8]. Within programming education, gamification has been used to encourage more time devoted to learning and immediate student assessment, whilst making it easier and more entertaining for students to partake in their programming education through various games and software that could guide students toward their success in programming [9, 10].

Studies investigating how effective gamification is in computer education have had varying results. While a substantial body of research shows positive effects on student motivation, engagement and participation, this hasn't consistently led to significant improvement in learning outcomes [5, 11]. Thus, a major gap exists within current research, as there's little insight into how participation rates among students in gamified learning environments impact academic performance among students. The inconsistencies between different studies show the critical need to design gamified environments correctly and utilise game elements that aid the learning of fundamentals, not detract from them.

The aim of this study is to examine the relationship between student participation in a gamified programming learning environment and academic performance in a first-year Internet Programming module. The research question guiding this study is: *What is the relationship between student participation in a gamified programming learning environment and academic performance in a first-year Internet Programming module?*

The remainder of this paper is structured as follows. Section 2 reviews prior research on the impact of gamification on learning outcomes in higher education programming education. Section 3 describes the design and implementation of the gamified Internet Programming learning environment. Section 4 outlines the research methodology used in this study. Section 5 presents the results, followed by a discussion of the findings in Section 6. Section 7 concludes the paper.

2 Literature Review

Several studies have investigated the impact of gamification on learning outcomes in higher education programming education. Table 1 summarises studies published in journal articles over the past 10 years examining the effect of gamification on student learning outcomes in programming-related higher education modules.

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Table 1. Studies investigating the impact of gamification on learning outcomes in higher education programming education

Study reference	Author(s)	Year	Country	Sample Size	Impact on Learning Outcomes
[9]	Fotaris et al.	2016	UK	106	Positive
[12]	Moreno and Pineda	2018	Colombia	45	Positive
[13]	Ortiz-Rojas et al.	2019	Mexico	89	Positive
[14]	Palaniappan and Noor	2022	Malaysia	29	Positive
[15]	Imran	2023	Not Mentioned	374	Positive
[16]	Mellado and Cubillos	2024	Chile	37	Positive
[17]	Du et al.	2016	Singapore	114	No Impact
[18]	Pilkington	2018	South Africa	67	No Impact
[19]	Zatarain Cabada et al.	2018	Mexico	69	No Impact
[20]	Cigdem et al.	2023	Turkey	96	No Impact
[21]	Khaleel et al.	2019	Malaysia,	90	Negative
[22]	Bernik et al.	2019	Croatia	201	Mixed
[23]	Huesca et al.	2023	Mexico	414	Mixed
[24]	Mellado et al.	2024	Chile	88	Mixed

As shown in Table 1, six studies report positive effects of gamification on student learning outcomes, suggesting that game elements such as points, leaderboards, and badges can improve learning performance. However, four studies report no significant impact, while three report mixed effects with one study even reporting a negative impact on learning outcomes. These inconsistent findings suggest that the effectiveness of gamification may depend on how gamified learning environments are designed and implemented.

Mere integration of game mechanics into gamified systems or applications does not inherently guarantee positive educational outcomes [25]. Instead, gamified systems should be systematically designed to promote desired behaviours [26]. Of the eight studies in Table 1 reporting no impact, negative, or mixed effects, only Pilkington [18] explicitly grounded the gamified learning environment in a theoretical model, namely self-determination theory [32].

Consequently, there is a need for theory-driven approaches to the design of gamified learning environments, particularly in introductory programming modules where strong engagement with foundational concepts is essential. To address this need, this study designed a gamified learning environment for a first-year internet programming module using principles derived from established gamification design frameworks and motivational theories. The design and implementation of the gamified programming learning environment are described in the following section.

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3 Gamified Programming Learning Environment

This section describes the design and implementation of the gamified programming learning environment used in this study. The design process followed was informed by two well-established gamification design frameworks namely the D6 gamification design framework proposed by Werbach and Hunter [27] and the Marczewski gamification design framework [28]. Both frameworks emphasise the importance of aligning gamification elements with user motivations and behavioural objectives when designing gamified systems.

The D6 framework [27] endeavours to integrate creativity and structure and to align the needs of individuals with technical feasibility and business imperatives. The framework consists of six steps, each starting with the letter 'D', as shown in Fig. 1.

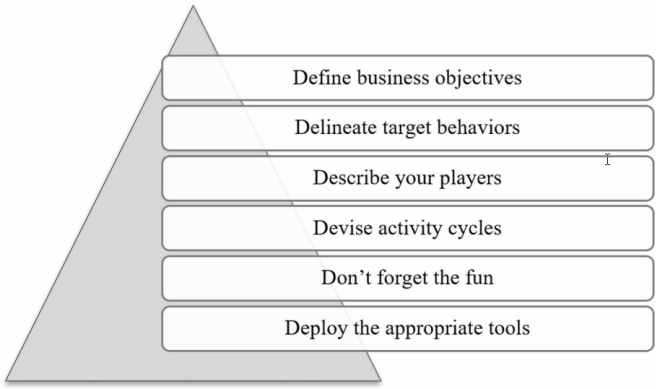


Fig. 1. D6 gamification framework

The Marczewski gamification design framework consists of three main steps, namely define, design and refine [28]. This framework emphasises the importance of understanding user motivations and player types in order to design gamification elements that effectively support engagement and participation.

Drawing on these frameworks, the design of the gamified programming learning environment was structured into three integrated stages namely: defining objectives, motivational design and deployment of the gamified system.

3.1 Defining objectives

Gamified systems typically pursue both experiential and instrumental outcomes [26]. Experiential outcomes relate to learners' subjective experiences, such as engagement and enjoyment, while instrumental outcomes refer to measurable learning achievements.

Accordingly, the primary objective of the gamified system was divided into experiential and instrumental components. The experiential objective aimed to foster an engaging and immersive learning experience that enhances student motivation, enjoy-

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ment, and active participation. The instrumental objective focused on developing students' practical web development skills in HTML5 and CSS3. The instructional content was therefore organised into two units. Unit 1 (HTML5) focused on the structural development of web pages, enabling students to create and organise content using standard HTML elements. Unit 2 (CSS3) focused on the visual presentation of web pages, allowing students to apply styling, layout, and design principles to enhance the appearance and usability of websites. Together, these units provided a foundation for building functional and visually structured web pages.

3.2 Motivational Design

The motivational design phase was used to achieve the experiential objective of the study by merging various motivational and game design frameworks, namely the Intrinsic Motivation RAMP [29], the HEXAD user typology [28], and the DMC pyramid [27].

Intrinsic Motivation RAMP Model. The Intrinsic Motivation RAMP model has emerged as a valuable framework for designing gamified systems [30, 31]. Proposed by Marczewski [29], the model integrates principles from self-determination theory [32] and Pink's drive theory of motivation [33]. While self-determination theory identifies autonomy, competence, and relatedness as key human motivational needs, Pink [33] similarly emphasises autonomy and mastery (similar to competence) and introduces purpose as an additional motivational driver. Marczewski therefore conceptualised these four motivational factors as RAMP: relatedness, autonomy, mastery, and purpose [29].

Within gamified systems, relatedness refers to the human need for social connection and belonging, which can be fostered through collaboration and community interaction [29]. Autonomy reflects individuals' desire for independence and freedom of choice, allowing users to decide how they engage with activities in the system [29]. Mastery involves the progression toward competence through increasingly challenging tasks and skill development, often associated with the experience of flow [29]. Purpose represents the human desire to contribute to meaningful goals or activities that extend beyond personal achievement [33]. Gamified systems that successfully address these four motivational drivers can foster intrinsic motivation, where participation in the activity itself becomes rewarding [30].

HEXAD user typology. The HEXAD user topology consists of six user types [28]. Following is a description of the user types of the HEXAD user typology, alongside the game design elements proposed by Marczewski to cater for the motivations of each user type [28].

Philanthropists exhibit motivation rooted in purpose, and are characterised by altruism and a willingness to contribute without seeking personal gain. Recommended design features include gifting, trading and knowledge sharing.

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Socialisers are driven by a desire for interpersonal connections and social engagement. They seek interactions with others and aim to foster social relationships. Design components include social comparison, social competition and social discovery.

Free spirits are primarily motivated by autonomy, which entails the freedom to express themselves and operate without external constraints. They enjoy opportunities for creative expression and exploration in a system. Design recommendations include exploratory tasks, nonlinear gameplay, unlockable content and creativity tools.

Achievers are driven primarily by a desire for proficiency and mastery. They strive to advance in a system by accomplishing tasks or demonstrating their capabilities through overcoming challenging obstacles. Design recommendations include challenges, certificates, skill acquisition, quests, and levels.

Players are incentivised by external reinforcements, such as rewards or recognition. Proposed design components include point systems, leaderboards and badges.

Disruptors do not want to participate in a gamified system and want to disrupt the system. Therefore, motivational game design elements are not applicable.

These player types align closely with the intrinsic motivational dimensions described in the RAMP model. For example, socialisers are primarily motivated by relatedness, free spirits by autonomy, achievers by mastery, and philanthropists by purpose. In contrast, the player user type is primarily motivated by extrinsic rewards such as points, badges, and other incentives. By combining the HEXAD player typology with the RAMP model, the gamified programming learning environment supported both intrinsic motivational needs and extrinsic motivational mechanisms.

DMC pyramid. The DMC pyramid created by Werbach and Hunter [27] is illustrated in Fig 2.

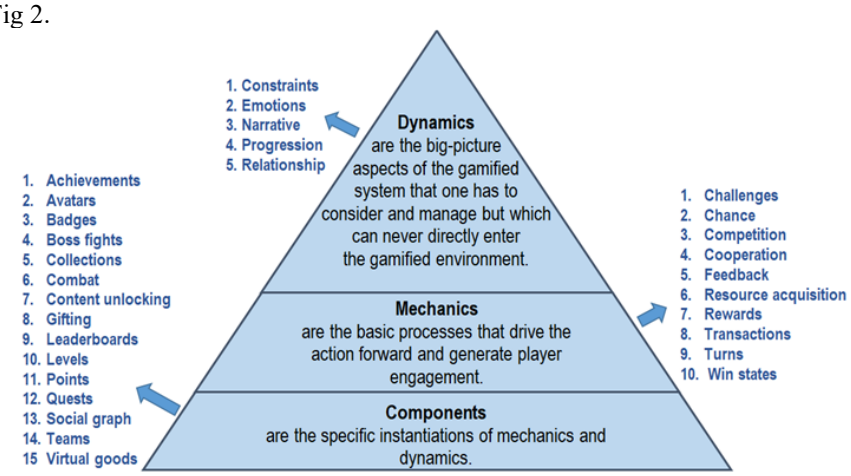


Fig. 2. DMC pyramid

It was created with the sole purpose of providing developers of gamified systems with a structured 'toolkit' consisting of common elements prevalent in gamification [27]. The primary aim of the framework is to delineate how diverse elements or components of games can be applied in various ways. The pyramid comprises 30 different game

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elements including game dynamics (top layer), game mechanics (middle layer) and game components (bottom layer), as shown in Fig. 2.

The motivation design phase of the study is summarised in Fig.3.

Type of motivation	**Intrinsic motivation dimension (RAMP)**				**Extrinsic motivation**
Key motivator	**Relatedness**	**Autonomy**	**Mastery**	**Purpose**	**Rewards**
HEXAD user type	Socialisers	Free spirits	Achievers	Philanthropists	Players
Recommended design features	Teams Social comparison Social competition	Exploration Fantasy Creativity	Learning new skills Difficult challenges Levels or progression	Meaning Knowledge sharing	Points Badges Leaderboards Virtual currency
DMC pyramid					
Dynamics	Relationship		Progression		
Mechanics	Competition Collaboration		Challenges Feedback		
Components	Leaderboards		Levels		Badges Points Leaderboards Virtual currency

Fig. 3. Theory based gamification design matrix

As illustrated in Fig. 3, the three frameworks were integrated to create a coherent motivational design in which each layer informed the next. The RAMP model established the four intrinsic motivational dimensions that the environment sought to address, while the HEXAD user typology translated these into specific learner profiles with corresponding design features. The DMC pyramid then provided the practical game elements through which these features were operationalised, including dynamics, mechanics, and components. Together, the three frameworks ensured that the motivational design was both theoretically grounded and practically actionable, targeting the full spectrum of student motivational needs rather than relying on a single motivational driver.

3.3 Deployment of the gamified system

Gamification implementation refers to the selection of gamification mechanisms appropriate for a specific problem or system and their subsequent deployment. According to Werbach and Hunter [27], this could either be by building an integrated system or using an existing gamified learning platform. Baikins [34] emphasises the necessity to

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investigate the appropriateness of available technology to facilitate development and implementation seamlessly.

The gamified learning environment for the current study, were employed by using a mix of gamified tools. Khan Academy [35] and Codecademy [36], supplemented teaching sessions for specific learning tasks and Kahoot! [37] and Gimkit [38] served to reinforce and assess student understanding. During the semester, students worked individually and in groups on gamified tasks and a collaborative project. Participation in gamified learning platforms was optional and not factored into formal assessments. Participation in gamified activities was voluntary because it allows adherence to the autonomy characteristic of the RAMP framework [30] and cater to the free spirit user type (Hexad framework) [28], who typically seeks freedom and intrinsic motivation for learning.

Khan Academy and Codecademy were selected because their structure and learning content most closely resembled the course module content, HTML and CSS. These platforms incorporate some of the core gamification principles, namely: (1) having clear goals for learners, (2) giving learners instant feedback on their progress and (3) having a clear progression to follow in learning materials. These core principles are aligned with the mastery dimension of the RAMP framework [30], supporting the achiever user type in the Hexad framework [28]. The badges and points that form part of these platforms also cater to the extrinsic motivational needs of the player user type [28].

To support relatedness, Kahoot! was incorporated as a gamified audience response system enabling real-time, competitive interaction during theory sessions [40]. This fosters social engagement and aligns with the socialiser HEXAD user type. Collaboration was further encouraged through a semester-long “Change the World” group project, where students developed a website for an innovative product or service. This activity supported teamwork and aligned with the philanthropist user type, which is motivated by contributing to others’ learning [28].

Finally, Gimkit was included to provide an additional, flexible participation channel aligned with the autonomy dimension of the RAMP model and the free spirit HEXAD user type. Its game-like, exploratory environment allows students to engage with content in a non-linear manner, promoting curiosity and intrinsic motivation [41, 42].

4 Methodology

4.1 Research design

A primarily quantitative research design was used to examine the relationship between participation in a gamified learning environment and student learning outcomes. This was complemented by a qualitative exploratory component to ascertain which gamified platforms were preferred by various HEXAD user types.

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4.2 Participants

The population for this study consisted of 304 students enrolled in a first-year Internet Programming module at a university in South Africa. The sample included students who participated in the gamified learning environment and for whom participation and academic performance data were available. A convenience sampling approach was used, as all students in the module were exposed to the gamified environment. For the qualitative component, a subset of 101 students voluntarily participated in group interviews to explore user type preferences.

4.3 Data Collection

Participation in the gamified learning environment was measured using behavioural participation indicators obtained directly from the four gamified platforms, rather than self-reported questionnaire data. Participation data for Kahoot! and Gimkit were extracted from the reporting features provided by the platforms. Kahoot! reports provided the total points earned by each student, while Gimkit reports provided the points earned during gameplay sessions.

Participation data for Khan Academy and Codecademy were collected during practical sessions with the assistance of student assistants. During these sessions, assistants recorded the total points accumulated by students on Khan Academy and the number of badges earned on Codecademy. These indicators represented students' actual interaction with the gamified learning activities.

To explore the preferences of different user types in relation to the gamified platforms, a subset of students was invited to voluntarily participate in group interviews. During these sessions, the HEXAD user type questionnaire, adapted from Tondello et al. [43], was administered to identify students' motivational profiles. Students were also asked to indicate which component of the gamified learning environment they found most motivating for sustained engagement. The resulting data were analysed descriptively and were not linked to the academic performance dataset.

4.4 Participation Indicators

Participation in the gamified learning environment was operationalised using the following indicators:

- Total Kahoot! points earned
- Total Khan Academy points earned
- Total number of minutes spent on Khan Academy
- Total Codecademy badges earned
- Average Gimkit percentage across all quizzes
- Overall gamification participation percentage

The overall gamification participation percentage was calculated by aggregating student engagement across the different platforms. This included: The total number of Kahoot! quizzes in which the student participated, the total number of Gimkit quizzes

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in which the student participated, the number of weeks the student completed activities on Khan Academy, the number of weeks the student completed activities on Codecademy. The aggregated total was then divided by the total number of participation opportunities to calculate the overall gamification participation percentage.

4.5 Data Analysis and Ethical Considerations

Statistical analysis was conducted using SPSS Statistics to examine the relationship between students' participation indicators and learning outcomes. A combination of inductive and deductive approaches were used to analyse qualitative data. Responses were coded systematically with NVivo 14 and checked for redundancy and convergence. Similar codes were grouped iteratively until a concise set of categories was formed. Ethical clearance was obtained prior to data collection, and participation was voluntary with informed consent and anonymised data.

5 Results

5.1 Qualitative results

Of the 101 students who participated in interviews, 29 were free spirits, 24 were achievers, 21 were philanthropists, 19 were socialisers, and 8 were players. The responses of students to the interview question are shown in Fig. 4.

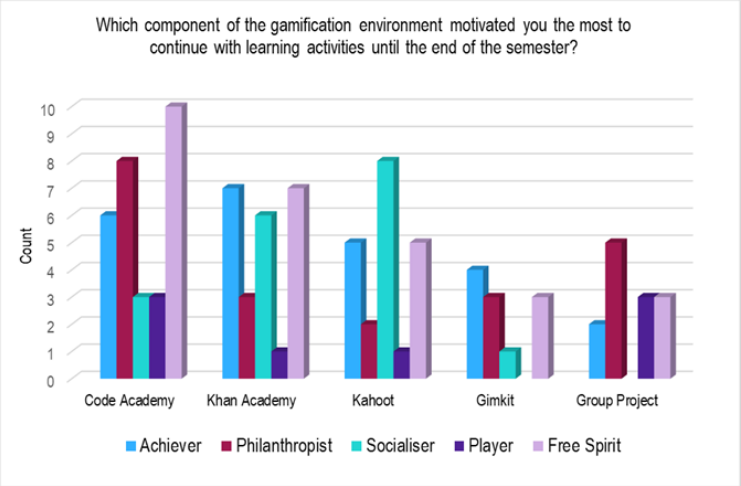


Fig. 4. Preference of gamified component by user type

Two user types, namely philanthropists (8 students) and free spirits (10 students), identified Codecademy as their most motivating platform. Achievers had the largest number of students (7) motivated by Khan Academy, which can be attributed to its hint-based,

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problem-solving approach that creates a challenging environment aligned with the mastery-driven nature of this user type. Socialisers had the largest number of students selecting Kahoot!, which is consistent with the HEXAD typology, as this user type is predominantly motivated by social collaboration and competition [28].

An interesting observation is that the group project was identified by philanthropists as having the second-highest motivational potential within the gamified learning environment, which aligns with the HEXAD user typology [28], as philanthropists are primarily motivated by opportunities for knowledge sharing and altruistic contribution.

5.2 Quantitative Results

Descriptive statistics for all study indicators are shown in Table 2. Gamification participation indicators was introduced in section 4.4 and academic performance indicators comprised of test mark 1, test mark 2, course mark, exam mark and final mark.

Table 2. Descriptive statistics

Study indicators	N	Min	Max	Mdn	Mean	STD
Test 1	281	0	100	79	65.34	20.57
Test 2	276	7	100	69	59.10	19.72
Course Mark	281	8	97	75	63.54	17.26
Exam Mark	249	2	100	73	60.40	25.60
Final Mark	249	24	99	73	64.27	18.00
CA_Tot_Badges	242	1	66	26	18.81	11.34
Gimk_Avg_Points	127	20	93	43	50.60	19.28
Kah_Tot_Points	247	578	46611	17312	15748.50	9919.55
KA_Tot_Points	258	104	91845	45820	37233.06	18886.89
Overall GP	269	1	80	37.37	27.77	16.28

CA= Codecademy, Gimk = Gimkit, Kah = Kahoot!, KA = Khan Academy, GP = Gamification participation

A Spearman's rank-order correlation was conducted to examine the relationships between students' gamification participation indicators and academic performance, with a non-parametric test selected based on the Shapiro-Wilk test confirming non-normal data distribution. These results are shown in Table 3.

Table 3. Spearman's rank-order correlations

Academic performance	N	Overall GP %	Kahoot! Tot Points	KA_Tot Points	CA_Tot Badges	Gimkit Avg Points
Test 1	r^s	0.509**	0.499**	0.419**	0.250**	0.289**
	N	269	247	258	242	127
Test 2	r^s	0.515**	0.401**	0.399**	0.274**	0.404**

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	N	266	244	256	242	127
Course Mark	r^s	0.689**	0.594**	0.523**	0.372**	0.364**
	N	269	247	258	242	127
Exam Mark	r^s	0.462**	0.457**	0.389**	0.193**	0.345**
	N	248	228	242	232	123
Final Mark	r^s	0.559**	0.522**	0.459**	0.274**	0.388**
	N	248	228	242	232	123

GP = Gamification participation CA= Codecademy, KA = Khan Academy
*** Correlation is significant at the 0.001 level (2-tailed).*

The strength of Spearman's rank-order correlations was interpreted using guidelines proposed by Cohen [44], where coefficients of approximately 0.20–0.39 indicate weak relationships, 0.40–0.59 moderate relationships, and 0.60–0.79 strong relationships.

The results revealed moderate to strong positive correlations between overall gamification participation percentage and all academic performance measures, including Test 1 (r_s = .509, p < .001), Test 2 (r_s = .515, p < .001), Course Mark (r_s = .689, p < .001), Exam Mark (r_s = .462, p < .001), and Final Mark (r_s = .559, p < .001). These findings indicate that higher levels of participation in the gamified environment were associated with improved student performance across all assessments.

When examining individual platforms, participation in Kahoot! showed moderate positive correlations with all performance measures, including Test 1 (r_s = .499, p < .001), Test 2 (r_s = .401, p < .001), Course Mark (r_s = .594, p < .001), Exam Mark (r_s = .457, p < .001), and Final Mark (r_s = .522, p < .001). Similarly, Khan Academy points were moderately correlated with academic performance, with coefficients ranging from r_s = .389 to r_s = .523 (p < .001). Gimkit participation demonstrated weak to moderate correlations with several performance measures, ranging from r_s = .289 to .404 (p < .001) while Codecademy badges showed weak positive correlations with performance, ranging from r_s = .193 to .372 (p < .001).

6 Discussion

The findings of this study are consistent with the majority of prior research on gamification in programming education, in that participation in the gamified learning environment was positively associated with academic performance across all assessment types. The moderate to strong correlations observed—particularly for course mark (r_s = .689) and final mark (r_s = .559) align with studies such as Fotaris et al. [9], Moreno and Pineda [12], and Mellado and Cubillos [16], while contrasting with studies reporting no significant, mixed, or negative effects [17 - 24]. A key distinction that may account for this divergence is the extent to which theoretical frameworks informed the gamification design. Only one of the eight reviewed studies (indicating no impact, mixed or negative impact) explicitly employed a motivational theory [18], whereas the present study grounded its design in the D6 framework [27], the HEXAD user typology [28], and the RAMP model [29], ensuring that game elements were systematically aligned

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with student motivational needs. The positive outcomes observed therefore lend empirical support to the argument that theoretical grounding is a meaningful differentiator between studies that yield positive effects and those that do not [25, 26].

At the platform level, Khan Academy points demonstrated consistently stronger correlations with academic performance (r_s = .389 to .523) than Codecademy badges (r_s = .193 to .372). This discrepancy reflects differences in the depth of cognitive engagement each platform promotes. Codecademy allows students to access complete solutions, enabling badge accumulation without deep engagement with the material. Khan Academy, by contrast, provides contextual hints rather than full solutions, compelling students to reason through problems independently. This distinction may also explain the null or negative outcomes reported by Zatarain Cabada et al. [19] and Khaleel et al. [21], where game mechanics did not incentivise deep cognitive processing.

Among the platforms, Kahoot! produced the strongest correlations with academic performance (r_s = .401 to .594). In this study, Kahoot! functioned as an integrated instructional medium, with each session combining explanatory content delivery with quiz-based retrieval practice, rather than serving solely as a formative assessment tool. The strong correlations may therefore reflect the cumulative benefit of active retrieval practice embedded within instruction [40], rather than the motivational effect of the quiz format alone. This offers a plausible explanation for the null results reported by Du et al. [17] and Cigdem et al. [20], where gamified tools were used primarily for engagement rather than as instructional vehicles. The qualitative finding that socialisers most frequently identified Kahoot! as their preferred platform further corroborates its effectiveness for relatedness-motivated learners.

Gimkit, targeting autonomy through competitive self-paced gameplay, demonstrated weak to moderate correlations (r_s = .289 to .404). While lower than some of the other platforms, these results remain statistically significant and suggest that Gimkit served a motivational maintenance function for autonomy-driven learners within the broader multi-platform ecosystem. Studies relying on a single gamified platform [17] may therefore underestimate gamification's potential across diverse motivational profiles. The multi-platform approach adopted here, aligned with the HEXAD typology and the RAMP model, accommodated a wider range of motivational drivers than any single platform could achieve in isolation, offering a practically actionable insight for educators designing gamified learning environments.

7 Conclusion

This study examined the relationship between student participation in a gamified programming learning environment and academic performance in a first-year Internet Programming module. The findings demonstrate that overall participation percentage in the gamified environment has a strong positive association with academic performance across all assessment types, contributing empirical evidence to a literature in which results have historically been inconsistent. The positive outcomes observed in this study are argued to stem from the theoretical grounding of the gamification design in the D6

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framework, the HEXAD user typology, and the RAMP model, distinguishing this approach from prior studies.

By incorporating multiple platforms aligned with key motivational drivers like autonomy, relatedness, and mastery, the study demonstrates the value of a theoretically informed and multi-dimensional gamification approach. The results further emphasise that active engagement, rather than passive participation, plays a critical role in student success, and that the design of gamification elements determines whether that engagement translates into meaningful academic outcomes.

In the context of rapidly evolving technologies, these findings underscore the importance of strengthening foundational computing skills through innovative and engaging teaching methods. The study offers a practical, theory-driven design approach that can guide educators and researchers in implementing gamified learning environments to support core programming competencies.

The limitations of this study include a correlational, single-institution design that precludes causal claims. The absence of a control group means that the contribution of gamification cannot be fully isolated from other instructional factors.

Future research can build on this work by applying the proposed design framework in different contexts and disciplines, as well as investigating the long-term impact of gamified learning on knowledge retention and skill transfer.

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The Cross-Module Integration Model (CMIM): Integrating Cross-Module Competencies in Undergraduate Computing Education

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Abstract. Undergraduate computing curricula are often organised as discrete modules, reinforcing disciplinary silos that do not reflect professional software development practice. This paper proposes the Cross-Module Integration Model (CMIM), a conceptual curriculum design that supports the integration of learning and assessment across traditionally siloed modules while preserving disciplinary learning outcomes. The model is illustrated through three second-year modules: Object-Oriented Programming, Information Security, and Communication Skills, demonstrating how technical development, security reasoning, and professional communication can be integrated within a shared project environment. CMIM uses a shared technical artefact as a boundary object through which students develop a software system while integrating security considerations and communicating technical decisions through professional presentations. Drawing on curriculum integration principles and established learning theories, the paper presents the structure, learning activities, and assessment architecture of CMIM. The study contributes a theoretically grounded model for operationalising cross-module competency integration in undergraduate computing education, offering a structured approach that institutions can adapt to improve curricular coherence and better align learning experiences with professional practice.

Keywords: Cross-Module Integration, Computing Education, Integrated Curriculum, Authentic Assessment, Project-Based Learning.

1 Introduction

Undergraduate computing programmes are typically organised into specialised modules that focus on developing distinct technical or professional competencies. Core subjects such as programming, information security, and professional communication are therefore often delivered and assessed independently within the curriculum. While this modular structure supports disciplinary depth and enables programmes to cover a broad range of knowledge areas, it can also result in learning experiences that are compartmentalised across modules. Therefore, students may develop competence within

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individual domains but encounter limited opportunities to apply these capabilities in a coordinated and integrated manner during their studies.

This separation contrasts with the nature of contemporary software development practice. In professional environments, activities such as system design, implementation, security analysis, and communication with stakeholders are closely interconnected and occur simultaneously throughout the development lifecycle [1]. Developers must not only implement functional systems but also evaluate potential security implications, justify design decisions, and communicate technical considerations to both technical and non-technical audiences [2-4]. When educational activities isolate these competencies into separate modules and assessment artefacts, students may graduate with strong disciplinary knowledge yet have limited experience integrating these skills within realistic development contexts.

A growing body of computing education research emphasises the importance of authentic and integrated learning environments that more closely reflect professional practice. Project-based learning and authentic assessment approaches have been widely used to create such environments by engaging students in sustained development tasks that require the application of multiple competencies. However, these approaches are typically implemented within individual modules, and relatively few structured models exist that support coordinated learning and assessment across multiple modules within a computing curriculum.

This study therefore seeks to address the following research question: *How can a shared project artefact be structured to support coordinated learning and assessment across multiple computing modules while preserving discipline-specific learning outcomes?*

Therefore, this study proposes the Cross-Module Integration Model (CMIM), a conceptual curriculum design intended to support coordinated learning across multiple modules within a computing programme. The model is illustrated through the integration of three second-year modules in a Bachelor of Science in Computer Science and Information Systems programme at a public university in South Africa*: Object-Oriented Programming (OOP), Information Security (IS)*, and *Communication Skills (CS)*. Within the proposed design, a shared software artefact acts as a boundary object through which students connect technical implementation, security reasoning, and professional communication within a single project context. Each module engages with the artefact from its own disciplinary perspective while maintaining its independent learning outcomes and assessment criteria.

The aim of this study is to conceptually articulate the CMIM and outline its theoretical and structural foundations for enabling integrated competency development in undergraduate computing education. Rather than reporting the results of an implemented intervention, the study focuses on the conceptual design of the model and the curriculum architecture required to support cross-module integration. Accordingly, the purpose of the paper is not to validate the effectiveness of the CMIM through student performance data, but to present and theoretically ground the model for cross-module integration.

The remainder of the paper is structured as follows. Section 2 reviews the theoretical background informing the proposed model and discusses the educational foundations

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underpinning integrated learning environments. Section 3 presents the architectural design of the Cross-Module Integration Model, including the curriculum alignment, project structure, and assessment architecture supporting the integrated project. Section 4 discusses practical considerations for implementing the model within modular computing curricula, followed by Section 5 which concludes the study.

2 Background

Undergraduate computing programmes are commonly structured as collections of discrete modules that focus on developing specific technical or professional competencies [5-6]. While this modular structure supports disciplinary organisation and administrative clarity, it can inadvertently reinforce fragmentation in the learning experience. Students encounter key concepts across multiple areas of computing, yet these competencies are often developed independently rather than in relation to one another [7]. Consequently, the curriculum may implicitly portray computing practice as a set of isolated activities rather than an integrated discipline in which multiple forms of expertise must be applied simultaneously. Resulting in fragmentation between technical, security, and professional competencies that students are expected to integrate in real-world computing practice.

This fragmentation is evident across core areas of computing education. Programming modules typically emphasise technical implementation, focusing on algorithmic reasoning, system design, and the application of programming paradigms [8, 9], while information security education often introduces concepts such as authentication, vulnerabilities, and controls through theoretical or conceptual approaches [10]. Similarly, professional communication modules develop students' ability to present and justify technical work, yet are frequently delivered independently of the systems students design and implement [11-12]. As a result, students may develop competence within individual domains but have limited opportunity to apply these competencies in a coordinated manner.

This separation contrasts with professional computing practice, where system development requires the simultaneous integration of technical implementation, security reasoning, and communication. Developers must design and implement systems while considering security implications, evaluating trade-offs, and communicating decisions to both technical and non-technical stakeholders. Addressing this disconnect requires curriculum structures that enable students to apply knowledge across disciplinary boundaries while maintaining the depth associated with individual modules.

Several established educational theories provide guidance for designing such integrated learning environments. Project-based learning provides a structure in which students engage with complex problems through the development of meaningful artefacts, encouraging the integration of multiple forms of knowledge within a sustained task [13-14]. Authentic assessment complements this approach by evaluating student learning through tasks that reflect professional practice, requiring students to demonstrate not only technical competence but also reasoning and communication [14-16]. Constructive alignment ensures coherence between learning outcomes, activities, and

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assessment, enabling integrated tasks to remain consistent with the objectives of individual modules [17]. Experiential learning further emphasises learning as an iterative process of experience, reflection, conceptualisation, and experimentation, supporting the development of understanding through structured engagement with tasks [18-19].

Interdisciplinary learning theory provides an additional mechanism for connecting knowledge across domains through the concept of boundary objects. Boundary objects are artefacts that can be interpreted across different disciplinary perspectives while maintaining a shared identity [20]. Within computing education, a shared software artefact can function in this role, enabling programming, security, and communication modules to engage with the same project while addressing distinct learning outcomes.

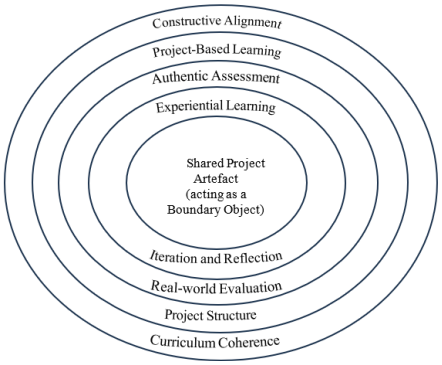


Fig 1: Theoretical foundations informing the Cross-Module Integration Model.

Figure 1 illustrates how the selected theoretical perspectives collectively inform the design of an integrated learning environment. At the centre of the model is the shared project artefact, which functions as a boundary object enabling interaction across modules. Project-based learning provides the overarching structure for sustained engagement, experiential learning supports iterative cycles of development and reflection, authentic assessment aligns evaluation with professional practice, and constructive alignment ensures coherence between learning outcomes, activities, and assessment across participating modules.

Taken together, these perspectives suggest that curriculum integration can be operationalised through a shared project structure centred on a common artefact. Project-based learning provides the overall learning environment, experiential learning supports iterative development, authentic assessment ensures alignment with professional practice, constructive alignment preserves module-level coherence, and boundary objects enable coordinated engagement across modules. Through this combination, students are able to design and implement systems, incorporate security considerations, and communicate their decisions within a single learning experience.

Building on these principles, the following section presents the design of the Cross-Module Integration Model (CMIM) and illustrates how these theoretical foundations inform its structure.

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3 Project Architecture

This section describes the conceptual architecture underlying the proposed cross-module integration. The architecture is derived through a structured curriculum analysis that identifies complementary competencies across the participating modules and translates these relationships into a coordinated project-based learning structure. Rather than immediately presenting the module, the section progressively constructs the architectural foundations that inform the final Cross-Module Integration Model (CMIM).

3.1 Curriculum Context

The three modules considered in this paper are delivered as concurrent, independent teaching units within the first semester of the second year of a BSc Information Technology programme. The programme follows a conventional modular structure in which each module is organised around a discrete set of competencies and assessed through independent artefacts. This reflects a widely observed pattern in undergraduate computing education, where technical, security, and communication competencies are developed within separate disciplinary boundaries.

Each module operates with its own delivery schedule, learning outcomes, and assessment criteria, with no formal mechanism for connecting competencies across modules. While each module functions coherently as an independent unit, students encounter these domains as parallel learning activities rather than as interrelated dimensions of professional practice.

The OOP module focuses on object-oriented design with an emphasis on system architecture and implementation, requiring students to develop functional software systems. The IS module addresses foundational security concepts, including secure system design, threat identification, and vulnerability analysis, typically through conceptual and analytical approaches. The CS module develops technical communication, professional presentation, and structured argumentation, enabling students to convey technical concepts to varied audiences.

The selection of these modules for the study is deliberate. Each represents a distinct yet interdependent dimension of professional IT practice, and computing curriculum frameworks consistently identify these competencies as core to graduate readiness [5,21] Their assessment structures further support integration: OOP requires system development, IS requires analysis of system vulnerabilities, and CS requires professional communication of technical findings. This alignment creates a natural basis for integration, allowing a single artefact to function simultaneously as a technical product, a subject of security analysis, and a medium for communication. It is this combination of professional complementarity, concurrent delivery, and aligned assessment that underpins the CMIM proposed in this paper.

3.2 Cross-Module Outcome Analysis

This section conducts a three-stage analysis of the learning outcomes distributed across the three participating modules. Relevant outcomes are first extracted from the formal

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module specifications and characterised according to Bloom's Revised Taxonomy [22] to identify the cognitive level at which each outcome operates. They are then categorised into competency clusters reflecting domains of professional computing practice relevant to the integrated project, and finally mapped against shared integration themes to demonstrate that a single project artefact can simultaneously serve as a vehicle for the assessment of outcomes from all three modules. The results of all three stages are consolidated in Table 1.

3.2.1 Extraction of Module Learning Outcomes

Prior to cross-module analysis, relevant learning outcomes were identified from each module's formal specifications and assigned module-prefixed references to support unambiguous cross-referencing. Outcomes that were foundational in nature but not directly enacted through project work, such as numbering systems, Boolean logic, and abstract communication theory, were excluded, as a project activity does not provide an appropriate vehicle for their assessment.

Each selected outcome was then classified according to Bloom's Revised Taxonomy [22] of the cognitive domain, which characterises the level of cognitive processing a student must engage in to satisfy the outcome. The taxonomy's lowest level, *Remember* (L1), is not represented among the selected outcomes: recall-oriented outcomes were excluded during the filtering stage on the grounds that rote recall is not meaningfully assessable through project work. The levels present in the selected outcomes therefore range from *Understand* (L2) and *Apply* (L3) to *Analyse* (L4), *Evaluate* (L5), and *Create* (L6). This classification provides a basis for aligning project tasks with the cognitive demands distributed across the three modules. The twenty selected outcomes, together with their Bloom classifications, competency categories, and integration theme contributions, are consolidated in Table 1. 2

3.2.2 Outcome Categorisation

The twenty selected outcomes represent competencies that, although distributed across three independent modules, belong to a smaller set of professional competency domains. Grouping these outcomes by domain clarifies the functional roles they play in integrated practice and establishes categories through which cross-module alignment can be systematically designed. Four competency categories are identified and reflected in Table 1: Technical Implementation, Security Reasoning, Professional Communication, and Professional and Ethical Practice.

These categories organise the outcomes by the type of professional competency they represent and the module domain from which they originate. The integration themes used in the subsequent mapping serve a different purpose: rather than grouping outcomes by competency type, they group outcomes according to the project-level activities through which multiple competencies are enacted simultaneously.

The central premise of this mapping is that a single shared project artefact can satisfy learning outcomes from all three modules. The integration themes were therefore designed to reflect points within the project where outcomes from different modules

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converge. Technical Implementation is operationalised as two themes, System Design and Architecture, and System Implementation, reflecting the distinction between design decisions and implementation activities, as well as the differing participation of IS outcomes across these stages. IS-LO1, IS-LO2, and IS-LO3 are primarily associated with the design phase, while IS-LO4 is enacted during implementation through the application of security controls. The remaining categories each yield a single theme, with minor terminological adjustments to reflect their enactment within the project context.

3.2.3 Cross-Module Outcome Mapping

Using the integration themes derived from the competency categories, the cross-module outcome mapping identifies the specific project activities at which outcomes from different modules converge. The integration theme columns (T1–T5) of Table 1 specify, for each theme, the outcomes addressed across all three module domains.

Table 1 demonstrates that the proposed cross-module project is not an aggregation of parallel module tasks, but an integrated activity in which technical implementation, security reasoning, professional communication, and ethical considerations are simultaneously enacted. Four of the five integration themes engage outcomes from all three modules, while the remaining theme reflects the natural asymmetry of disciplinary contribution. This mapping provides the evidential basis for the project structure and informs the design rationale presented in the following section.

3.3 Design Rationale

The cross-module outcome mapping presented in Section 3.2 establishes that a single shared project artefact can simultaneously satisfy formally assessed learning outcomes from all three participating modules. This raises a design question: on what principles should such an artefact be constructed, and how should integration across independent modules be organised?

The central principle of the CMIM is that integration operates through a shared artefact evaluated using discipline-specific instruments. Each module retains full pedagogical independence, with its learning outcomes, teaching approach, and assessment criteria unchanged.

What changes is the context in which these outcomes are enacted. Rather than being demonstrated through isolated tasks, outcomes are enacted within a common project environment requiring their simultaneous application. The project is therefore not a merged module or jointly assessed task, but a shared operational context in which each module's competency demands are independently yet concurrently enacted.

Integration is achieved through a shared software system functioning as a boundary object, as established in Section 2. Each module engages with the same artefact from its disciplinary perspective without altering its outcomes or assessment. OOP treats it as the primary implementation vehicle, requiring system design, development, and testing. IS treats it as the subject of security evaluation, analysing vulnerabilities and applying countermeasures. CS treats it as the basis for professional communication, requiring justification of technical and security decisions. The artefact therefore serves

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Table 1. Cross-module outcome map: selected learning outcomes, Bloom's Revised Taxonomy levels, competency categories, and integration theme contributions**.**

Module-Ref.	Learning Outcome	Bloom	Competency Category	T1	T2	T3	T4	T5	Primary Project Deliverables
OOP-LO3	Knowledge of UML as design tools	L2	Technical Implementation	✓			✓		Iteration 2.1 - Planning Document
OOP-LO5	Knowledge of fundamental OO principles	L2		✓		✓			Iteration 3 - Development Demonstration
OOP-LO7	Knowledge of file handling and exceptions	L2			✓	✓			
OOP-LO8	Analyse problems and write OO solutions	L6		✓	✓				Iteration 2.1 + 3
OOP-LO9	Develop, code, test, and debug OO solutions	L6			✓	✓			Iteration 3 - Development Demonstration
OOP-LO10	Apply OO concepts to solve programming problems	L3			✓				
OOP-LO11	Create event-driven OO solutions	L6			✓	✓			
OOP-LO13	Solve file and exception handling problems	L3			✓	✓			
OOP-LO14	Use UML in analysis and planning phases	L3		✓			✓		Iteration 2.1
OOP-LO15	Apply version control in project development	L3			✓			✓	Iteration 3 - Version Control Repository
IS-LO1	Knowledge of core security concepts (CIA, authentication)	L2	Security Reasoning	✓	✓	✓			Iteration 2.2 - Security Analysis Report
IS-LO2	Awareness of security threats and controls	L2		✓		✓			
IS-LO3	Identify security threats and vulnerabilities	L4		✓		✓	✓		
IS-LO4	Identify controls to mitigate security threats	L5			✓	✓	✓		Iteration 2.2 + Iteration 3
IS-LO5	Act according to the IT professional code of conduct	L3	Professional. & Ethical Practice				✓	✓	Iteration 3 + Iteration 4 - Oral Presentation
CS-LO2	Critically analyse sources and apply to real-world scenarios	L4	Professional Communication				✓		Iteration 4 - Oral Presentation
CS-LO3	Interpret business communication in organisational context	L2		✓		✓	✓		
CS-LO4	Knowledge of business communication process & audience analysis	L2		✓		✓	✓		
CS-LO8	Apply communication skills through presentations and reports	L3		✓		✓	✓		
CS-LO10	Take professional responsibility for work and decisions	L5	Professional & Ethical Practice				✓	✓	Iteration 4 - Reflective Team Contribution
			Bloom's level range per theme	L2-6	L2-6	L2-6	L2-5	L3-5	
			Contributing outcomes (n=)	10	9	12	10	3	
			Contributing modules	OOP, IS, CS	OOP, IS	OOP, IS, CS	OOP, IS, CS	OOP, IS, CS	

Note: Integration Themes - T1: System Design & Architecture; T2: System Implementation; T3: Security Integration; T4: Technical Communication & Decision Justification; T5: Professional & Ethical Practice. Bloom's Levels - L2: Understand; L3: Apply; L4: Analyse; L5: Evaluate; L6: Create.

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simultaneously as a technical product, a security subject, and a communicative object. This interpretive flexibility allows the shared artefact to function as a boundary object, supporting different disciplinary perspectives while maintaining a consistent project identity across modules.

Five theoretical frameworks inform the design of the CMIM. Project-Based Learning [13–14] provides the structural foundation through a sustained development task. Experiential Learning [18–19] supports iterative cycles of implementation, reflection, and refinement. Authentic Assessment [15–16] ensures evaluation reflects professional practice. Constructive Alignment [17] preserves coherence within each module, and Boundary Objects [20] explain how a single artefact can support multiple disciplinary interpretations while maintaining a consistent identity.

These frameworks operate as complementary design principles. Project-based learning establishes the shared environment, experiential learning structures progression, authentic assessment aligns evaluation with practice, constructive alignment maintains module integrity, and boundary objects enable coordinated engagement. Together, these principles underpin the five integration themes identified in Table 1: System Design and Architecture, System Implementation, Security Integration, Technical Communication and Decision Justification, and Professional and Ethical Practice.

3.4 Structural Architecture

This section describes the structural architecture through which the CMIM is operationalised. The architecture is organised into five layers, each corresponding to a distinct functional component of the model: the *Input Layer* establishes the curricular foundations; the *Project Design Layer* defines the shared artefact and iterative structure; the *Cognitive Progression Layer* describes how learning unfolds across iterations; the *Assessment Architecture Layer* specifies formative and summative mechanisms; and the *Reflective Integration Layer* closes the experiential cycle. These layers operate in a coordinated arrangement across the project timeline rather than in strict sequence.

3.4.1 Input Layer

The Input Layer encompasses the curricular and contextual foundations of the CMIM. Its primary components, established through the outcome mapping in Section 3.2, are the selected learning outcomes, the competency categories, and the integration themes through which cross-module alignment is operationalised.

In addition, the Input Layer incorporates practical curriculum constraints that bound the model's design. These include institutional parameters, group composition (teams of three to four students), and the semester timeline within which all project iterations must be completed. These constraints directly influence the scope and complexity of the shared artefact and the structure of project activities.

The concurrent delivery of the three modules provides the operational condition for cross-module integration. In practice, coordination is supported through a shared LMS project space that hosts project materials, communication, and resources across all modules without requiring structural modification to individual module delivery.

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3.4.2 Project Design Layer

The Project Design Layer defines the shared software artefact and the iterative structure through which it is developed. The project is organised into four iterations, beginning with Iteration 1, which introduces the project scope and system requirements within the OOP module. Iteration 2 integrates OOP and IS through the development of system design artefacts and security analysis, followed by Iteration 3 which focuses on system implementation and testing. The final phase, Iteration 4, is situated within the CS module and involves the professional presentation and communication of the completed system.

The student-selected project domain must satisfy structural requirements, such as user management, role-based access, record management, and data persistence, to ensure sufficient complexity to engage all integration themes. This layer operationalises Project-Based Learning, with the shared artefact functioning as the central object of sustained inquiry.

3.4.3 Cognitive Progression Layer

The Cognitive Progression Layer describes how learning unfolds across the project through an experiential learning cycle. The project iterations align with the phases of the cycle, beginning with concrete experience through initial engagement with the problem domain in Iteration 1, followed by conceptualisation and reflection through system design and security analysis in Iteration 2. Iteration 3 emphasises active experimentation through implementation and testing, while Iteration 4 focuses on reflection and abstraction through the evaluation and communication of design decisions.

The project as a whole enacts an iterative cycle of action, reflection, and refinement. Movement between phases is not strictly linear, as implementation challenges may prompt revisiting earlier design or analysis stages. This layer embeds experiential learning within the structure of the project rather than treating it as a separate activity.

3.4.4 Assessment Architecture Layer

The Assessment Architecture incorporates both formative and summative mechanisms. A key formative component is the planning document developed during Iteration 2, which serves as a gate requirement for progression to implementation. Lecturer feedback provided at this stage enables students to refine their design and address issues prior to development.

Summative assessment is distributed across the three modules through discipline-specific rubrics applied to the shared artefact. The OOP module evaluates system design, implementation quality, and robustness; the IS module assesses the identification of vulnerabilities and application of security controls; and the CS module evaluates the professional communication of the completed system.

Each module assesses the same artefact from its own disciplinary perspective using independent criteria. This arrangement ensures that assessment remains aligned with module outcomes while reflecting the performance of an integrated, authentic task.

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3.4.5 Reflective Integration Layer

The Reflective Integration Layer closes the experiential cycle by requiring students to reflect on their design decisions, development process, and collaborative work. Reflection is embedded within the CS module through structured evaluation of students' ability to justify their technical and security decisions and to articulate their learning.

This layer operationalises the reflective and conceptual phases of the experiential learning cycle and reinforces the integration of technical communication and professional practice within the project context.

3.5 Cross-Module Integration Model (CMIM)

This section presents the Cross-Module Integration Model (CMIM) as the structural synthesis of the outcome analysis, design rationale, and architectural specification developed in Sections 3.2–3.4. The model should be interpreted as a coordinated architecture rather than a linear process: five functional layers operate in a mutually reinforcing arrangement, centred on a shared software artefact that enables integration across the participating modules.

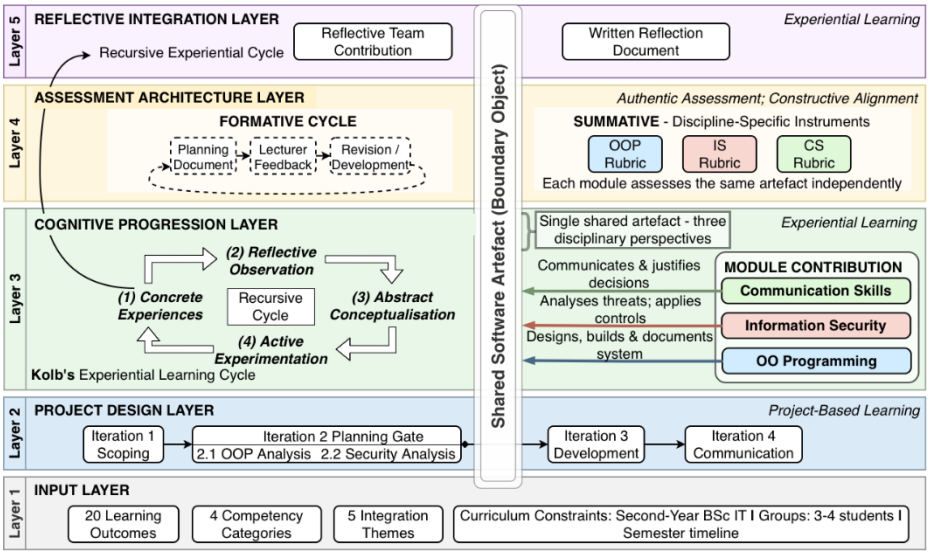


Fig 2: Cross-Module Integration Model (CMIM): Five-Layer Structural Architecture

Figure 2 provides a visual synthesis of the model by illustrating how the five architectural layers interact through a shared artefact and how module participation is distributed across the structure. It highlights three key aspects less apparent in textual description: (1) the central role of the shared artefact as the point of integration across all layers, (2) the alignment between project iterations and cognitive progression, and (3) the simultaneous but differentiated engagement of the three modules. The model is therefore not intended as a sequential workflow, but as a layered system in which

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integration emerges through the interaction of structural, cognitive, and assessment components.

The central organising element of the CMIM is the shared software artefact, which functions as a boundary object [20] and as the focal point of the project-based learning environment [13-14]. It maintains a consistent identity across all layers, while each module engages it from a distinct disciplinary perspective. It is simultaneously a technical product, a subject of security analysis, and a medium for professional communication, enabling integration without requiring structural modification to individual modules

The five layers operate through coordinated interactions across the project timeline. The Project Design and Cognitive Progression layers are closely coupled, with the iteration structure providing the temporal framework for the experiential learning cycle. Each iteration aligns with a phase of learning, supporting progression from design to implementation and reflection.

A second interaction occurs between the Cognitive Progression layer and the Assessment Architecture. The planning document in Iteration 2 functions as both a formative mechanism and a transition point between conceptualisation and implementation, enabling refinement before development. The Reflective Integration layer completes the experiential cycle by embedding reflection within the project and enabling iterative refinement.

A defining property of the CMIM is that it achieves integration without disrupting module autonomy. Each module retains its own learning outcomes, delivery structure, and assessment criteria. OOP engages the artefact as a technical implementation task, IS as a security evaluation context, and CS as the basis for professional communication. Integration is achieved through the shared operational context rather than the merging of modules or assessments, preserving constructive alignment while enabling cross-module coherence.

The five integration themes identified in Table 1 provide the functional links through which integration is enacted. These themes represent points where outcomes from multiple modules converge on shared activities. Technical implementation and security integration are coupled within system design and development, while communication and justification are addressed through structured presentation. Professional and ethical practice is embedded across the full project lifecycle.

Taken as a whole, the CMIM demonstrates that cross-module integration can be achieved through a shared artefact and coordinated project structure without requiring changes to module specifications or assessment frameworks. Its effectiveness depends on three conditions: concurrent module delivery, genuine outcome convergence, and an artefact of sufficient complexity. Where these conditions are met, the CMIM provides a theoretically grounded and practically implementable model for integrating technical, security, and professional competencies within undergraduate computing education.

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4 Implementation Consideration

The CMIM was developed within a specific institutional context, but its underlying structure is replicable. Three conditions are necessary for any viable instance. Participating modules must be concurrently delivered within the same semester and year. Their learning outcomes must contain genuine convergence points, at least one integration theme simultaneously addressable by all three modules, verifiable through the outcome mapping procedure described in Section 3.2. And the shared artefact must be sufficiently complex to engage all modules' competency demands authentically. Where these conditions are not met, integration should not be attempted.

4.1 Module Role Classification and the CMIM function

The architecture distinguishes three functional roles, defined by each module's relationship to the shared artefact. The Core Module (CM) is responsible for generating and evolving the artefact, defining domain requirements, driving the project timeline, and carrying primary technical assessment weight. The Secondary Core Module (SCM) applies a domain-specific analytical lens to the artefact without owning its design, embedding a secondary competency layer such as security, ethics, or governance. The Parallel Module (PM) uses the artefact as the basis for authentic professional communication and reflection, assessed independently of its technical or analytical dimensions.

This role classification is based on functional dependency rather than disciplinary hierarchy. The CM is designated as primary because it produces the shared artefact on which all subsequent activities depend. The SCM and PM engage with this artefact in complementary ways: SCM evaluates and extends it through domain-specific reasoning, while PM focuses on the articulation and justification of decisions embedded within it. This reflects the structure of professional practice, where system development underpins analysis, and both support communication.

A key condition for effective integration is meaningful outcome overlap between CM and SCM. The stronger this intersection, the deeper the integration during development. In contrast, PM does not require direct technical overlap, but rather that the shared artefact constitutes credible and assessable communicative content within its assessment framework.

A CMIM configuration is considered viable when the participating modules are delivered concurrently, exhibit sufficient overlap between CM and SCM outcomes, and involve a shared artefact that is complex enough to support both development and analysis. Under these conditions, the relationships illustrated in the model can be expressed functionally as follows:

$$CMIM(A) = PM \circ SCM \circ CM(A)$$

This expression captures the logical relationship between modules: the core module produces the artefact, the secondary module analyses and enriches it, and the parallel module supports communication and reflection. The composition reflects logical dependency rather than strict sequencing, as these activities may occur iteratively throughout the project lifecycle.

For the instance presented in this paper:

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$$CMIM(A) = CS \circ IS \circ OOP(A)$$

In this configuration, Object-Oriented Programming is designated as the core module because it is responsible for the design and implementation of the shared software system that underpins all subsequent activities. Information Security engages with this artefact analytically, examining vulnerabilities and applying security principles, while Communication Skills focuses on the articulation and justification of technical and security decisions.

While presented here as a three-module configuration, the model is extensible. Multiple secondary modules may operate on the shared artefact, each applying a different analytical perspective. Similarly, one or more parallel modules may be incorporated where appropriate, provided that the artefact supports meaningful communication and reflection within their respective assessment contexts. The core requirement remains that all participating modules maintain a functional dependency on the shared artefact.

A parallel module is not strictly required. Where no dedicated communication module (or soft skill module) is available, a two-module configuration remains viable provided that the core and secondary modules exhibit sufficient overlap, and the artefact supports meaningful analytical engagement. In such cases, communication and justification may be embedded within the analytical module itself. While this configuration preserves the core integration mechanism, it represents a reduced form of the model, as it omits the explicit communicative and reflective dimension.

4.2 Artefact and Assessment Requirements

The shared artefact must be sufficiently developed to function as a boundary object across all participating modules. Rather than being defined by specific technical components, this requirement is characterised by three properties. First, the artefact must be non-trivial, requiring engagement with higher-order design and creation processes. Second, it must be multi-interpretable, allowing secondary modules to apply analytical perspectives to meaningful design decisions. Third, it must be professionally authentic, ensuring that communication and reflection are grounded in realistic and contextually relevant scenarios.

Assessment remains distributed across modules. Each module evaluates the shared artefact independently using its own discipline-specific criteria, preserving constructive alignment without requiring shared rubrics or joint marking structures. The primary coordination requirement is timeline alignment, particularly ensuring that formative feedback at key planning stages is available prior to development. Where modules rely primarily on examinations or isolated exercises, implementation of CMIM may require the introduction of a project-based assessment component within the core module.

5 Conclusion

This paper proposed the Cross-Module Integration Model (CMIM) as a structured approach to addressing fragmentation in undergraduate computing curricula. By coordinating learning across Object-Oriented Programming, Information Security, and Communication Skills through a shared project artefact, the model demonstrates how

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technical, security, and professional competencies can be developed within a single integrated learning experience. Grounded in project-based learning, experiential learning, authentic assessment, constructive alignment, and boundary objects, the CMIM provides a theoretically informed and practically implementable design. Its key contribution is a structured mechanism for achieving cross-module integration while preserving disciplinary autonomy and existing assessment structures.

This study is conceptual and does not report on an implemented intervention. As such, the model has not yet been empirically evaluated in terms of its impact on student learning, engagement, or performance. In addition, the design is situated within a specific institutional context involving three concurrently delivered second-year modules, which may limit generalisability to programmes with different structures or scheduling constraints. While the theoretical grounding and outcome mapping provide a strong basis, the model's practical effectiveness and scalability remain to be validated in real teaching environments.

Future work will focus on implementing and evaluating the CMIM within the participating modules. Further research will explore its adaptability across different institutional contexts, module combinations, and levels of study, as well as broader implications for curriculum design. Through this, the CMIM has the potential to support more coherent and practice-aligned computing education.

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Redesigning an Honours Research Methodology Module Using a Hybrid Agile Approach to Enhance Student Self-Efficacy: An Analytical Autoethnography

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Abstract. Novice researchers (4th year Honours students) often find research methodology and research project modules overwhelming due to their low confidence in conducting academic research. This study presents an analytical autoethnography from the course coordinator's perspective of a fourth-year research module using a hybrid agile framework in the production process of a research output. The lecturers implemented a scaffolded, continuously developed systematic literature review (SLR) research paper. Focused on self-efficacy, this module redesign engaged the student to actively, and iteratively "build" the research report throughout the year with frequent feedback from the lecturer, supervisor and peers. Students were required to reflect on three aspects of their journey: the concept of research, the process of writing and the effectiveness of peer evaluation. The results showed that student self-efficacy improved, especially due to the peer review process. The feedback students received from peers and supervisors on their progress was initially experienced as personal criticism, however it was later perceived as constructive, improving research competence. The redesigned module demonstrated that iterative assessment design supports research learning.

Keywords: Agile education, Constructivism, Experiential learning, Redesign principles, Research Methodology, Self-Efficacy

1 Introduction

Research methodology and producing a research report (or paper) is part of most of the Information System curricula of the third or fourth year of studies at the South African institutions of higher education as it is mandated by the Council of Higher Education for an NQF level 8 programme [1]. The purpose for this mandatory research component is to build research capacity, develop critical thinking and to promote advanced specialisation in the field. In this instance, in the field of Information Systems.

Teaching research methodology is well-reported in literature [2–4]. Literature revealed that students often struggle with the abstract concepts associated with academic research [5]. Literature on teaching research methodology further show that students often lack motivation [3, 5], fail to see the relevance of the course [3], they feel overwhelmed with the course content and difficulty [3], they have misconceptions about what academic research is and their attitude towards the module is poor [3].

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A number of pedagogical approaches have been reported on before such as a prototype project based learning [6], learning strategy [5], the use of active learning [3, 4], experiential learning [3, 4], student centred approaches [4, 7], the use of Generative AI in teaching social research methodology [8], learning analytics [9] and cooperative learning, service learning and online learning methods [3].

Contributing to the challenges of the pedagogy of research methodology and research report writing, is the role and responsibilities of the supervisor. Supervision is a multifaceted undertaking. Wright et al. (cited in [10]) describe that a supervisor is responsible for quality assurance, a supportive guide, research developer, mentor and knowledge expert. Supervisors, often having a heavy supervision load – in addition to teaching and other administrative duties – often struggle to fulfil all these roles and responsibilities. Abeid et al. [10] reported that barriers for postgraduate supervision include: managing multiple responsibilities at the same time, slow or delayed feedback, challenges in choosing a suitable supervisor and research topic, struggling to manage supervisor–mentee relationships due to limited research experience, inadequate access to necessary resources, insufficient funding for research activities and unclear guidelines and expectations.

This paper reports on a module redesign initiative for a fourth year (Honours level) research methodology and research report module. The previous design followed a siloed approach where students completed the theory of research methodology in discrete assignments, such as writing a problem statement and different research strategies and data collection methods, before producing a systematic literature review report. This approach limited the opportunity for iterative learning and timely feedback. The module redesign involved the implementation of a scaffolded, continuously developed SLR research paper. Focused on self-efficacy, a central component of Social Cognitive Theory [11], this module redesign proposed a hybrid agile framework to actively engage students to iteratively "build" the research report throughout the year with frequent feedback from the lecturer, supervisor and peers. The aim of this study is to critically reflect a module redesign that is focused on improving student self-efficacy in understanding and conducting academic research, improving student time management, increasing feedback, reduce supervisory overload and the hope of mitigating over-reliance on Large Language Models (LLMs). In achieving this aim, the researcher aims to answer the following research question: *"How did a scaffolded, hybrid agile module redesign support the development of student self-efficacy in an Honours-level research module?"*

The rest of the paper is structured as follows: Section 2 provides a summary of the theoretical underpinning employed in the module redesign. Section 3 provides an overview of the context of the module being redesigned and a description of the problematic implementation of the module. Section 4 provides a description of the redesigned module. Section 5 details the analytical autoethnography research methodology followed to report the findings in the paper. Section 6 presents the findings and reflection of the course coordinator, and section 7 presents the discussion of the findings. Sections 8 and 9 presents the changes made to the framework for implementation in 2026, limitations of the study and concluding remarks.

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2 Theoretical Underpinning

The study employed three theories as a foundation for the redesign of the module. Each of these theories will be discussed in the following sections below.

2.1 Self-efficacy as a component of Social Cognitive Theory

Self-Efficacy is a central component in Social Cognitive Theory (SCT) which was developed by Bandura [12]. Self-efficacy is described as a person's belief or confidence in their ability to achieve their goals [13]. Bandura [12] explains that self-efficacy is informed by four sources: performance accomplishments that is achieved through the mastery of experiences, vicarious experiences where individuals learn by observing others, verbal persuasion where "people are led, through suggestion, into believing they can cope" [12], and physiological/emotional states where individuals judge their own capabilities, strengths and vulnerabilities.

2.2 Constructivist and Experiential Learning

Constructivism is described as both a philosophy and a learning theory [14]. At its foundation are three principles [14]: active knowledge construction where students are active recipients of information and construct knowledge based on their previous experiences and conceptual models. Secondly, students derive meaning as it is understood from their point of view and finally constructivism is a student-centred and the students' context of learning influence their learning processes.

Therefore, given the three principles of constructivism, constructivism supports the phases of experiential learning (EL) which asserts that individuals learn by doing something concrete. Learning is grasped through concrete experience (interacting with the phenomenon) and abstract conceptualisations (drawing conclusions after reflecting on the experience), and experience is transformed through reflective observation (review and reflect on the experience) and active experimentation (apply what has been learned from the process) [15].

2.3 Hybrid agile approach in research methodology and project module

Agile methodologies are well known in industry in the software development context. The main principle of an Agile Methodology is that a project is broken into smaller time boxed tasks based on user stories, continually updated based on frequent feedback delivered in iterations [16]. The use of agile principles in education is known as Agile Education [17].

In the context of the study, a hybrid agile approach is adopted in the production process of a single research output. The hybrid-ness refers to the acknowledgment that not pure agile principles can be implemented due to the constraints of the educational environment such as assessment deadlines. Therefore, in the context of this study, the

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research project is broken into smaller iterations on which students receive regular incremental feedback to "building" the research report.

3 Context and Case Description

This section describes the problem setting of the case in Section 3.1, followed by how the module was presented previously (prior to 2025) in Section 3.2 and the challenges experienced with this approach in Section 3.3.

3.1 Setting

The module that was redesigned, is a fourth year (Honours level) research methodology and research report (according to a thesis structure) module offered by one of the leading universities in South Africa. The module is compulsory for all the students enrolled for the programme. The classes are presented in person with eight classes per semester presented (approximately) every second Friday (public holidays and recess period are accounted for), starting in February to May for semester one, and July to November in semester two. The number of student ranges between 145 to 200 per year. Each supervisor (lecturers from the Department who has different areas of expertise/research areas) is responsible for six to eight students, apart from a few supervisors that will supervise more than eight students (when students approach them directly). The module is presented throughout the year and contributes 30 credits to the programme total. Prior to 2024 the module used to be structured in two mostly distinct semesters.

The first semester focused on the concept of academic research, the different research strategies, data collection methods, data analysis methods for both quantitative and qualitative data. The understanding of students was assessed through assignments and class activities. Oates et al. [18] is used as the prescribed textbook to cover the research methodology theoretical components.

The second semester focused on a particular research strategy – a systematic literature review (SLR). Students were required to complete a systematic literature review based on a research question they have chosen from the list of research questions (made available on Google sheets) proposed by the supervisors. Each supervisor had to propose eight research questions. Refinement/modification of the research question is allowed during consultations with the chosen supervisor. The textbook of Cherry et al. [19] is prescribed for the SLR component.

In 2024 there was a slight change to the content presentation schedule and students started earlier (April) with their SLRs, and the theory of research methodology were revisited in the second semester. The rationale for this realignment of content presentation was to address students' challenge with fragmented learning – the theory of doing IS research were (in their minds) far removed from doing the IS research (in the form of the SLR paper). Due to SLR papers being readily accepted for conference publications in the Information Systems domain, students were required to submit their examination submission of their research report (which is in a thesis structure) in the Springer conference template. In 2024, ten Springer publications (with students as first authors

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and supervisors as second authors) were accepted for publication by the time students were finished with the course. Another, approximately 30 publications of student outputs followed in 2025.

3.2 High level schedule of content presentation

Table 1 details the high-level presentation of the module components prior to 2024 and the redesign of 2024.

Table 1. High level content presentation schedule

Date	**Prior to 2024**	**2024**
February	What is Information Systems Research? Oates et al., Chapters 1 – 6	
February	Problem statement, research question, research strategies, Oates et al. - Chapter 7 - 12	Research Strategies, Oates et al. – Chapters 7-12
March	Problem statement, research question, research strategies, Oates et al. - Chapter 10 Oates Chapter 10	Data Collection methods, Oates et al. – Chapters 13-20
March	Research strategies: Design and Creation, Experiments, Action Research, Ethnography, Oates et al. – Chapters 8, 9, 11, and 12	Executing SLR, Boland et al. - Chapters 1 – 3
March	Data collection methods, research paradigms and data analysis: Observations and interviews, Oates et al. – Chapter 13, 14, 17 - 20	Doing SLR, Boland et al. - Chapters 4-6
May	Data collection methods, research paradigms and data analysis: Questionnaires, Oates et al. – Chapters 15, 17 - 20	Doing and writing up your SLR, Boland et al. - Chapters 9,11
May	Summary of the research process – from problem statement, research questions to findings and conclusion, Oates et al. – Chapter 16	Semester test, Oates et al. - Chapters 1 - 20
May	Executing a SLR Research paper, Boland et al. - Chapters 1 – 3	SLR Workshop
July	Doing SLR, Boland et al. - Chapters 4-6	Abstract, conclusion, future research
August	Doing and writing up of SLR, Boland et al. - Chapters 9,11	Conceptual contribution
August	Workshops – practical hands-on exercises	Qualitative data collection and analysis
September	Workshops – practical hands-on exercises	Quantitative data collection and analysis
October	Preparing for examination submission	
November	Exam submission	

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Table 2 below illustrates the assessment schedule for the major assessments of the module prior to 2024 and 2024.

Table 2. Assessment schedule

Assessment prior 2024	**Content**	**Assessment 2024**	**Content**
Group assignment (May) (Marked by Module lecturer)	Data collection methods and analysis	Individual assignment 1 (April) (Marked by Module lecturer)	Research paper from Introduction to Research Methodology, including data extraction table
Individual assignment 1 (June) (Marked by Module lecturer)	Research process	Individual assignment 2 (June) (Marked by Supervisor)	Research paper: Revision of assignment 2 sections, and data extraction and analysis results, findings and discussion.
Individual assignment 2 (August) (Marked by Module lecturer)	Research paper from Introduction to Research Methodology, including data extraction table	Individual assignment 3 (Marked by Supervisor)	Research paper: Revision of assignment 2 sections, and data extraction and analysis results, findings and discussion.
Individual assignment 3 (September) (Marked by Supervisor)	Research paper: Revision of assignment 2 sections, and data extraction and analysis results, findings and discussion.		
Examination assignment (3 November) (Marked by Supervisor and additional marker)	Research paper revision of individual assignment 3 with abstract and conclusion (in thesis structure)	Exam submission (27 October) (Marked by Supervisor and additional marker)	Research paper revision of individual assignment 3 with abstract and conclusion in Springer template

As indicated in Table 2, prior to 2024, students had a group assignment on data collection and analysis techniques that involved collecting data from peers, followed by three individual assignments. Each of these assignments were related to the research report. All these assignments were marked by the module lecturers, apart from individual assignment 3 which was marked by the supervisor and the examination assignment that was marked by the supervisor and a second marker from the department's supervisory team. This implies that each supervisor will approximately mark sixteen examination submissions, eight of their own students, and eight as the second marker.

Furthermore, Table 2 shows that in 2024, in line with the revised schedule presented in Table 1, the students started earlier with their research report assignments. The only difference to prior years were that supervisors were asked to mark assignments 2 in addition to marking assignments 3 and the exam submission as previously.

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3.3 Challenges with the original module designs

From the student evaluation feedback received in previous years, the author's experience as a supervisor on the module, and as a lecturer on the module, students' and supervisors' challenges were observed. The following sections report on these challenges.

Student challenges. The following student challenges were identified:

1. Students do not understand the need for the module.
2. Time management is a huge issue, as the module is labour intensive, but also most of them are working full time, therefore they need to balance work with academics.
3. Students underestimate the amount of time needed to succeed in the module.
   a. The module requires students to read many research papers, whilst coming to grips with understanding and implementing the basic research skills.
   b. Students need to work consistently on their research paper, but often only complete section just before the due date.
   c. Students wait until just before the due date to engage with their supervisors to ask for feedback.
4. Students, especially since the introduction of LLMs, demonstrate a dependency on using LLMs due to two main reasons:
   a. Students question their self-efficacy, as they feel "they cannot say it any better".
   b. Students are running out of time and use LLMs as a "quick" fix to complete their work.

Supervision challenges. The following main supervisor challenges were identified by the module coordinator in her role as supervisor, and as a lecturer engaging with other supervisors on the module.

1. Supervisors struggled with workload as they have a minimum of 6-8 Honours students to supervise, in addition to Master and PHD students, their lecturing load, administrative responsibilities in the department, and their own research.
2. Due to workload challenges, supervisors often provide inconsistent or feedback, or no feedback.
3. Supervisors are frustrated with students only contacting them days before the due date for feedback.
4. Supervisors sometimes missed the emails from the students or forgot to respond.

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Lecturer challenges. The lecturers on the module often experience the following main challenges:

1. Lecturers do not always know what the supervisor told the student, which might result in conflicting feedback. Also, if the supervisor cannot give feedback, the lecturing team needs to know to either prompt the supervisor for feedback or ensure that they give appropriate feedback to the student.
2. Lecturers do not have an overview of student progress, only the snapshots that were submitted as part of assignments, or when students consult (their own students or any other student in the class).
3. The lecturing team also noticed issues with marking biasness (in some instances), where the examination mark of the supervisor, differed significantly (more than 10%) from the second marker. This was addressed by the external moderator; however, it was noted as a challenge.
4. Penalising students for AI use is becoming more difficult as the tools are becoming smarter.

4 Module Redesign

The 2025 course coordinator, having been part of the module as lecturer for the past two years, and having a background in implementing a Hybrid Agile approach in the capstone module, set out to address the challenges she observed. Section 4.1 introduces the design principles followed by the course coordinator for the 2025 redesign of the module. The module redesign has resulted in a revised schedule, which is presented in Section 4.2. Section 4.3 details the key interventions implemented as part of the module redesign.

4.1 Design Principles

The following principles informed the module redesign. These principles were informed by the theoretical underpinning components discussed in Section 2. The discussion of the principles in relation to the theoretical underpinning is presented in Section 7.

1. Students need to engage actively and frequently to improve their understanding of academic research, and to build their competencies in executing the research process.
2. To create transparency between students and supervisors and the lecturing team, a central platform needs to be used by students and supervisors to provide feedback.
3. A minimum of two weeks need to be given to the supervisor for feedback.
4. Students submit only one assignment – the complete research report which gets marked by the supervisor.
5. Frequent feedback needs to be given to the student to improve on their incremental development of their research report.
6. Reducing the workload of the supervisors is imperative.
7. Bias marking of examination submissions needs to be minimised.

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4.2 Revised high level schedule for 2025

Table 3 illustrates an extract of the 2025 schedule.

Date	Lecture	Class work	Homework
March	Data Analysis, Problem Statement, Introduction to theory Part II, Chapters 7-20 (Oates, 2024)	Printed summary of five articles (pre-reading provided by the supervisor on the research question chosen)	Complete Section 1 and 2 of Google doc **Word Article** template, **Print Sections 1 and 2**
March	Executing a SLR	Peer review Section 1 and 2	Update Sections 1 and 2, highlighting changes in blue, and additions in yellow, @ comment supervisor by 11 April, finalise search string
April	Doing SLR, Endnote training	Merge results, review papers, Practice data extraction, Introduction to data analysis	Continue review and data extraction, start Section 3, 4, Download 25% papers on Google drive, highlighting changes in blue, and additions in yellow
April	Data analysis	Practice data analysis, Introduction to data synthesis. Introduction to data visualisation	Download 100% of papers on Google drive, Start/continue with data analysis, continue working on Sections 3 and 4, Complete synthesised table in Section 4, Print one page of synthesised table and bring to class
May	Findings	List outline of discussion of findings, Write one sub-section of findings, Peer review	Complete Sections 3 and 4, highlighting changes in blue, and additions in yellow, print Section 3 and 4 and bring to class
May		Peer review Section 4	Update Section 4 with feedback. Review theories/frameworks identified in bibliometric analysis… construct a conceptual model/mapping of findings in Section 5, @ comment supervisor, print theory

Table 3 illustrates that student peer review not only class exercises, but also aspects of the research report before supervisor feedback is requests. Furthermore, specific due dates are communicated by when students need to contact their supervisors.

4.3 Key Interventions

The following key interventions were implemented:

1. Following the 2024 schedule of starting the SLR research paper earlier, the course coordinator made a Google folder for each of the supervisors containing sub folders for each of their students. In each student folder, there were two documents: the Homework document – used to develop the search string, and the research report

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template. The supervisor folder was shared with each supervisor, and each student received a link to their own folder.
2. To assist supervisors with managing their student feedback, students were instructed to only work on the documents in their assigned folders, this way the supervisor has a central repository for all their students' work and there is a central place where feedback was collected. Students were encouraged to tag the supervisor through the @comment in Google Docs which assigns the work to the person tagged (the supervisor) who is alerted via email.
3. Supervisors only need to provide feedback on the incremental progress of the student's research report until it is completed.
4. Class exercises were based on elements of the research report that allow students to understand and have the competencies to complete the section in the research report.
5. Class exercises were marked by the peer using a rubric provided and the course lecturer marked the quality of feedback given by the peer (quantitative and qualitative feedback).
6. The course schedule communicated specific due dates for students to complete a specific section of the research report, when peer reviews will happen and the latest date, they should ask for feedback from the supervisor (to give the supervisor two weeks to respond).
7. To improve the quality of the iteration to be reviewed by the supervisor, the course coordinator brought in peer reviews for each section of the research report which were completed in class. Final assignment and examination reviews were also conducted as part of the peer reviews in class.
8. Students had to construct a portfolio of evidence containing all their class activities.
9. At the end of the course, the students had to reflect on their growing understanding of the academic research process, their ability to improve their academic writing and the value of feedback (peer, lecturer and supervisor) by referring to their class activities and their interactions with their supervisor and lecturer.
10. The assessment plan was restructured where the portfolio accounts for 25%, assignment accounts for 25%, the semester test accounts for 25%, and the final 25% is for quizzes and the industry day assignment. The restructure was designed to decrease the pressure in the development part of the research report.
11. The portfolio assessment mark consists of 10% for the peer review mark, 15% for the quality of peer review given, 25% each for the three reflective essays: the research process, academic writing and the effectiveness of feedback (peer, supervisor and lecturer).
12. To further reduce the workload of the supervisors, examination submissions were marked by a marker that is not the supervisor.
13. In the place of a second marker, internal moderators were assigned to the markers, where one moderator will look at the marking of one examiner – to ensure consistency of marking and completeness of marking. If issues were found, this is referred to the external moderator.
14. The external moderator reviews the examination submissions where the internal moderator indicated errors, and any other papers he/she would like to review.

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5 Research methodology

This research adopted a qualitative analytical autoethnographic research design [20, 21] from the course coordinator's perspective. Adopting an analytical autoethnographic strategy is appropriate as this paper reports on the lived experiences of the course co-ordinator who was part of the teaching context in which the module was redesigned using a hybrid agile approach. Anderson [21] explains that there are five key features of analytical autoethnography.

First, the researcher must be a complete member (CMR) of the phenomenon under study. In this instance, the researcher has spent two years as a lecturer on the module and one year as course coordinator. Furthermore, the researcher was a supervisor of the students of the course for the past ten years.

Second, analytic reflexivity describes the extent to which the researcher is aware of their bidirectional influence on the research situation. The researcher is a colleague and part of the supervisory team for this module. However, as the researcher is the assigned course coordinator for this module, she was very cognisant of the workload of the other supervisors, who had their own modules assigned. Therefore, none of the interventions should add to the workload of her peers, else it seems that she is deferring her workload to them. Also, she was often in the middle of the conflict between the supervisor and student due to challenges experienced due to challenges experienced by both: students complained about the lack of feedback or timely feedback by the supervisor, and supervisors complained about the lack of performance of students.

Third, narrative visibility of the researcher refers to the visibility of the researcher in the research situation. This aspect was made easy through the support of the Head of Department, and technology. Every week, at the departmental meeting, the researcher reported back what task has been done by the student, and what is expected next from the student and supervisor. This served as gently reminders regarding to the supervisors of what to expect. Also, using the learning management system, where all supervisors also receive the communication, the researcher reminded students of the same. Also, the learning management system was used to provide general feedback regarding issues that was observed by the researcher during the semester.

Fourth, dialogue with informants beyond the self, calls for the researcher to touch base with "data" or "others" [21]. This is needed to avoid the research becoming self-absorbed. In this instance, the researcher frequently engaged with colleagues to "test" ideas, or discuss a problem observed. There were several consultations with lecturers assigned to the module previously, and supervisors, to discuss the impact of changes and the feasibility of initiatives. This was important to get the buy-in from most peers, before embarking on changes that can affect their workload, and their student success.

Fifth, commitment to theoretical analysis refers to the researcher not being content with just understanding "what is going on" but is also concerned with generalisation. Section 8 describes the changes the researcher implemented in 2026, based on the lessons learnt from her experience that can be used by other educators in their contexts. On a horisontal level, this hybrid agile approach is not just appropriate for teaching research methodology for IS students, this approach can be used in all disciplines.

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On a vertical level, this approach was informed by the third-year capstone module, however, it has been extended by a few peers to Masters and Doctoral level.

6 Findings and Reflection

The subsections below report on the findings of the experience of the course coordinator. Since the researcher reflects on her lived experiences of the module redesign, the findings are presented in first person.

6.1 Development of Self-efficacy

Students were required to reflect on their understanding of the research process and their development in academic writing. From the student reflections, the conversations with students and the interactions I had with students I learnt that most of the students could notice how they have grown to understand the research process, and how they have developed in their writing by providing explicit examples of their "earlier" work (class activities, earlier versions of their research report). This contrasts with how they felt about their ability to write in the beginning, where they felt overwhelmed with the reading, the ability to synthesise their writing.

6.2 Iterative building of the research report with continuous feedback

The students welcomed the scaffolded, iterative nature of "building" the research report. They also supported the idea of only having one assignment as opposed to many smaller assignments. This addressed the "fragmented" nature of the previous module designs where student struggled with aligning the assignments to the research report.

Continuous and incremental feedback was provided in the form of peer review and supervisor feedback as shown in Table 3. Lecturer feedback was given in the form of some class activities that were marked by the lecturer or feedback in the "check-ins".

Students reported that initially the peer review feedback they gave (and received) were not perceived as helpful. They reported that they felt that they were not qualified to give feedback to their peers, they did not want to criticise their "friends" or was ashamed to share their work with peers, in case it was not up to standard. However, peer feedback was reported as being one of the greatest sources of learning. As per the schedule in Table 3, peer feedback was conducted regularly on the pieces written at home (parts of the research report), usually before supervisor feedback was requested, and on appropriate class activities. Students reported that they started noticing that they can give feedback beyond spelling and grammar and can comment on the content. They also reported that they noticed that their peers were on the same level as them, so they did not have to be ashamed of their own work. Furthermore, they noticed what was missing in their own work by reading their peers' work.

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Supervisor feedback was initially perceived as negative, and demoralising as some students were not used to abrupt and to the point feedback. I explained to them that feedback should be seen as constructive and they must keep in mind supervisors have limited time. They provide feedback mostly on the things that should be fixed, to improve the product.

From a lecturing point of view, I provided feedback to my own students, but also to those students who reported not receiving feedback from their supervisors. Furthermore, I provided feedback, mostly editorial feedback on the progress of the research report when I spot editorial mistakes, or lack of progress.

6.3 Challenges and tensions

The overall redesign of the module was well received by the supervisors and students. However, the following challenges and tensions have been identified:

1. The students struggled with the fluidness of "building" the research report. Even though specific due dates were communicated, verbally and on the schedule, they struggled with the idea that they don't have to submit anything, just continue working on the same document.
2. Not all students and supervisors liked the idea of working on Google Drive. Students were sometimes restricted to their work devices which did not allow Google Drive access, and some supervisors preferred that the students emailed them their work.
3. Some supervisors got annoyed with the @comment function, as students often tagged them multiple times in the same document for the same review.
4. Some supervisors felt it is unfair that they cannot mark their own student's work for the examination.

7 Discussion

This study aimed to reflect on a module redesign intended to enhance student self-efficacy in research, maintain academic integrity of the course, improve time management, increase feedback, reduce supervisory overload, and mitigate over-reliance on AI writing tools. The principles followed in the redesign of the module were reported in Section 4.1. The scaffolded learning [14], implemented by explaining the research concept, practicing it in class and implementing it in the research report which got updated based on iterative feedback, supported the iterative nature of "building" the research report in line with an agile approach [17]. The research report represents a research paper that is publishable, meeting the real-life requirement for an EL project [22]. The redesigned schedule, presented in Section 4.2, supported the development of student self-efficacy by structuring learning into iterative, and achievable milestones.

Artino [13] offered five examples of how the principles of academic self-efficacy can be applied: (1) help students to set clear and specific goals, (2) set goals that test the boundaries of capabilities, but are not unattainable, (3) provide feedback, (4) calibrate self-efficacy, (5) use peer modelling to build self-efficacy. The module redesign supported the achievement of each of these principles. Firstly, the structured schedule

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presented in Table 3, supported self-efficacy development by providing students with clear and specific goals. These goals were iterative in nature, in line with the hybrid agile methodology [17]. The frequent feedback received, as described in Section 6.2, attempted to create an environment that ensured that students knew the goals are attainable. Furthermore, the lecturer reiterated in class, and through learning management system (LMS) announcements that reinforce mastery experience source of self-efficacy [12] that research is a process, and academic writing is a skill that should be learnt. This further supports principles two and three of self-efficacy [13]. In support of principle four, the students indicated in their reflections that the peer review was the most unexpected, and effective source of learning, which supports the vicarious learning source of self-efficacy [12]. The peer review and the review of the peer feedback given by the lecturer to the peer reviewers, supports the principle of constructivism which encourages collaboration and peer knowledge construction [14]. The final principle of self-efficacy, reducing anxiety, was supported through the assessment plan where the marks for the development of the research report, which included marks for feedback received from peers, supervisors and lecturer, feedback given to peers which was marked by the lecturer accounted for only 25% of the portfolio mark. The rest of the portfolio mark accounted for the reflections of the students. Reflective practices are encouraged by constructive learning theory [14].

Figure 1 conceptualises the module redesign framework generated by Gemini AI using a prompt derived from the discussion section, without the references. Figure 1 illustrates how the module redesign aims informed the eight redesign principles. It further shows how the five self-efficacy principles, from Artino [13], were applied in the module. The hybrid agile approach is aligned with the scaffolded learning cycle that iteratively built the research report, based on iterative and incremental feedback loops.

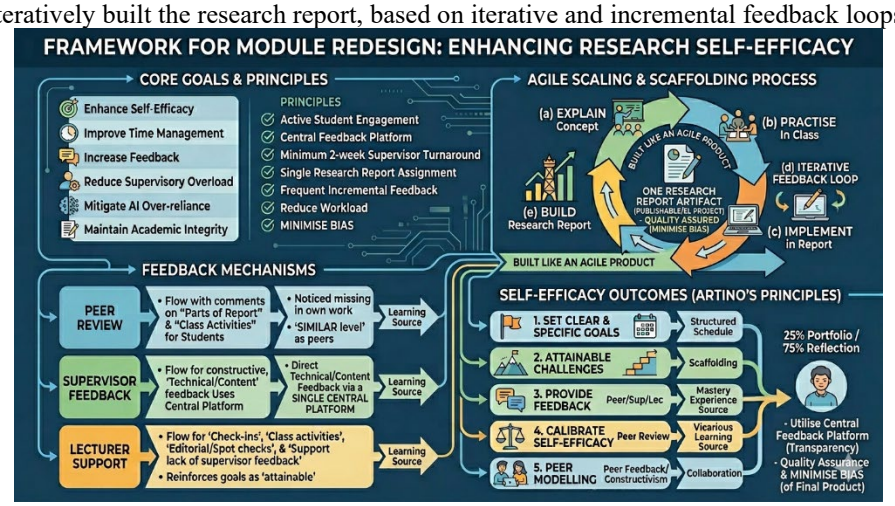


Fig. 1. Module redesign framework generated by Gemini AI.

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8 Changes informed by Lessons Learnt

Following this experience, the following changes was made for the 2026 implementation.

1. Introduce fixed uploads as snapshots into the LMS. This aspect is psychologically important to students in response to addressing challenge 6.3.1 and it reinforces the time boxing concept associated with an agile approach [17]. It is also easier for the lecturer to conduct her "check-in" from a central platform. Although the marks associated with these uploads are minimal, it easy to capture it in the LMS.
2. Using an AI writing assistant as part of Blackboard LMS to assist with feedback. A roleplay AI assistant was developed by the lecturer with the simple instruction of "act as a critical academic reviewer" and with guard rails such as "only highlight areas for improvement, do not write any paragraphs". The students' initial prompt was to "identify strengths and weaknesses" for the given section.
3. Extend the module content by adding an empirical aspect to the research, in the form of an expert evaluation of the conceptual models produced from the SLRs. This will increase the publishability of the research outputs.

9 Conclusion

The findings of this study suggest that the redesigned module, using a hybrid agile approach, helped to improve students' self-efficacy and engagement with the research process. Although the iterative approach improved the time management of students to continually engage with their research report, some student struggled without fixed "uploads" that signalled fixed due dates. Consequently, one lesson learnt from this was to introduce snapshot uploads with specific due dates by the lecturer. By breaking the research project into smaller, structured tasks and providing continuous feedback from peers, supervisors, and the lecturer, students were able to gradually build their research reports. This process supported experiential learning and constructivist principles, as students learned by doing, reflecting, and improving their work throughout the year.

In addition, the inclusion of self-efficacy principles such as clear goal setting, regular feedback, peer learning, and reflection appeared to increase students' confidence and reduce anxiety. The use of lower-stakes, process-based assessment also helped to create a more supportive learning environment, while reducing pressure on supervisors and encouraging student independence. Overall, the hybrid agile approach shows potential as an effective way to teach research methodology, especially in helping students manage their work and develop confidence in conducting research.

The redesigned framework proposed, with the changes implemented in 2026, is generalisable for scenarios where a complex writing task need to be executed, regardless of the domain. It is important to get the buy-in of all the stakeholders, as to not cause too many disruptions to existing work processes.

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The main limitation of this paper is that it only reports on the experience of the lecturer. Future research, following ethical clearance, will report on the themes derived from the qualitative analysis of the reflections of the students.

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Integrate Practice with Theory: A Design Model for Introducing Applied Security Thinking in Information Security

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Abstract. Curriculum constraints, large class sizes, limited human resources, and the difficulty of introducing offensive security at entry-levels, result in undergraduate information security modules remaining largely theory-dominated. Traditional approaches often advocate for the inclusion of practical components to support the theoretical foundation; however, this is not always a viable option in introductory modules. There is therefore a need to introduce applied security thinking without requiring specialised infrastructure, additional credits, increased staffing, or advanced technical skills. Rather than requiring students to attack systems, such an approach may support the development of secure development reasoning within normal coursework through sound pedagogical design. This paper proposes a feasible design model that outlines a structured set of practical interventions aligned with existing learning outcomes and assessment criteria. It is anticipated that such an approach will increase student engagement and provide additional opportunities for students to internalise and integrate key security concepts relevant to the professional environment. The contribution of this paper is a transferable design model that can be implemented by other institutions within existing undergraduate curricula to support the transition from conceptual understanding to applied security awareness.

Keywords: Active Learning, Applied Security Thinking, Curriculum Design, Information Security Education

1 Introduction

The field of Information Security is inherently practical; however, in educational contexts, it is often presented in a predominantly theoretical manner due to constraints such as sensitivity of the domain, limited resources, and the complexity of realistic environments.

In this paper, a collection of practical interventions considered suitable for fostering applied learning within a second-year undergraduate Information Security module is presented. These interventions allow students to engage with simulated problems, where they are challenged to think through real-world situations, and are collectively presented as a model. Importantly, the proposed

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interventions are designed to be feasible within the typical constraints of undergraduate modules, including limited resources, large class sizes, and the absence of specialised infrastructure. The purpose of the proposed model is to ensure that the interest of students new to the security domain is stimulated, while creating a learning experience that extends beyond purely theoretical engagement.

This study, therefore, investigates the following research question: *How can applied security thinking be introduced into a traditionally theoretical undergraduate Information Security module using lightweight, scalable, and resource-conscious interventions?*

While the individual pedagogical strategies used in this study are established within cybersecurity education literature, the contribution of this paper lies in the structured integration of these lightweight interventions into a coherent and scalable design model tailored for resource-constrained undergraduate Information Security modules.

In the subsequent sections, the theoretical grounding of the paper is presented (Section 2), followed by the research design adopted by the researchers within the educational setting (Section 3). In Section 5, the existing theory is extended by proposing a compilation of suitable practical interventions that can be readily integrated with the theoretical material of the Information Security module under discussion. Section 6 introduces Bloom's Revised Taxonomy as the evaluation framework adopted in this study. Section 7 then presents the proposed Practical Intervention Model, while Section 8 concludes the study.

2 Theoretical foundation

The theoretical grounding supporting the introductory Information Security module, is provided by the prescribed textbook, which presents the fundamental concepts upon which practical implementations may be built. Approaches suitable for computing education, and specifically within the security domain, are presented in a table format, together with a condensed evaluation of each. Lastly, Bloom's Revised Taxonomy (BRT) is introduced to support the evaluation of the selected approaches within the overall design.

2.1 Information Security

The prescribed textbook for the Information Security module is the *CompTIA Security+ Guide to Network Security Fundamentals* [1]. The textbook provides a comprehensive introduction to information security concepts aligned with the CompTIA Security+ framework, covering core areas such as confidentiality, integrity, and availability, as well as topics including cryptography, identity and access management, network security, risk management, and incident response. As such, the textbook serves as a strong theoretical foundation for students,

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exposing them to both fundamental principles and industry-relevant knowledge expected at an entry-level in cybersecurity.

The delivery of the content within the module, as guided by the textbook, is predominantly conceptual in nature. While students are introduced to key terminology, frameworks, and security controls, opportunities to engage with these concepts in applied contexts remain limited. This reinforces a knowledge-driven learning experience, where students may understand security principles in theory but struggle to recognise how these principles manifest in practical computing environments. Within the context of this paper, the prescribed textbook therefore represents the theoretical baseline upon which the proposed design model builds, with the intention of supplementing conceptual understanding through feasible, integrated practical interventions.

2.2 Computing as an Application Environment

Table 1 relays a selection of practical implementation type approaches that is suitable to support learning of information security concepts. This allowed a foundation from which the lecturer could select approaches in support of the theory. From these suggestions a model emerged, in the particular context of the subject module's offering, taking into consideration that selections should support students' understanding of Information Security, and allow their interest to guide them towards future learning, as is the case with this group of 2nd-year students, who build on this foundation in the honours year, for these individuals continuing with post-graduate studies.

Table 1. Possible approaches to integrate practice with theory

Approach	Description	Key reference	Evaluation
Virtual Labs	Realistic simulated environments where students may perform attacks/defence tasks which align with theoretical concepts	Vykopal, Čeleda, Seda, Švábenský and Tovarňák [2]	Provides strong experiential learning and exposure to realistic scenarios. However, requires specialised infrastructure and may introduce technical complexity not suitable for 2nd-year students, making it less feasible for integration into constrained modules.
Case Studies	Real-world incident scenarios as opportunities to apply theoretical knowledge to authentic situations	Mehall [3] Hosseinzadeh, Ratan, Shnaigat, Edwards, Verma, Niknami and Dadich [4]	Effective for contextualising theory and promoting critical thinking. However, often remains discussion-based and may not result in active practical skill development, limiting its ability to fully support applied learning.
Paper Exercises	Discussion-based simulations of incidents – where responses require decision-making under uncertain circumstances	Vykopal, Čeleda, Švábenský, Hofbauer and Horák [5]	Easy to implement in large classes and supports analytical reasoning. However, lacks hands-on engagement and may not sufficiently bridge the gap between theory and practice on its own.

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Approach	Description	Key reference	Evaluation
Challenge-Based Learning	Students need to solve open-ended security problems by integrating conceptual and procedural knowledge	Galdames-Calderón, Stavnskær Pedersen and Rodriguez-Gomez [6]	Encourages active problem-solving and deeper engagement. However, may require careful scaffolding to remain appropriate for students with limited prior technical experience, suggesting the need for guided rather than fully open-ended implementations.
Flipped Classroom	Students study theory in their own time – before class allows class time to be spent on applied activities	Zainuddin, Zhang, Li, Chu, Idris and Keumala [7]	Promotes active participation and engagement during contact sessions. However, relies heavily on student preparation and is most effective when combined with structured in-class activities.
Game-Based Learning	Game-based scenarios which allow engaging contexts where applying security concepts is required	Hendrix, Al-Sherbaz and Victoria [8]	Increases motivation and engagement while introducing decision-making in a low-risk environment. However, may oversimplify complex security concepts if not carefully aligned with learning outcomes, requiring integration with other instructional approaches.
Hands-on Learning	The adjustment of task difficulty in support of progression from theory to practice	Mukherjee, Le, Chow and Susilo [9]	Supports skill development through direct application of concepts. However, may require additional time and resources to implement effectively, particularly in large classes with limited support.
Collaborative Work	Team-based activities (competition) which reflect real-world security collaboration	Kornegay, Arafin and Kornegay [10]	Reflects real-world teamwork and enhances problem-solving through collaboration. However, uneven participation among group members may limit individual learning if not carefully structured.
Guided Labs	Practical tasks evolving into independent, complex problem-solving – through step-by-step guidance	Burton [11]	Provides scaffolded practical experience suitable for early-stage learners. However, may limit independent exploration if overly guided, highlighting the importance of balancing structure with exploratory learning.
Reflective Activities	Analysis of decisions and strategies after practical intervention to allow a deepened understanding	Rayavaram, Ukaegbu, Abbasalizadeh, Vellamchetty and Narain [12]	Encourages deeper understanding and critical reflection. However, does not provide direct practical engagement on its own and is most effective when combined with applied activities.

While each approach offers a particular value, the evaluation indicates that no single method sufficiently addresses the theory–practice gap within the constraints of a 2nd-year Information Security module. This supports the need for a combined and context-sensitive approach, as proposed in this study, where multiple complementary interventions are integrated to achieve a balanced and feasible solution.

Some of the approaches are not suitable in environments with limited resources e.g., virtual labs require specialised infrastructure, while hands-on learning may require additional time and resources. Others address the theory–practice gap only partially e.g., paper-based exercises lack hands-on engagement, and reflective activities do not provide direct practical experience. Certain approaches may also risk addressing concepts at a superficial level if not

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carefully implemented e.g., care must be taken not to oversimplify concepts in game-based learning, while others remain primarily discussion-based and do not offer direct practical engagement e.g., case studies support applied learning only to a limited extent.

These observations highlight the need for careful evaluation and selection of approaches to ensure that the theoretical foundation of the module is effectively supported through integrated practical implementation.

2.3 Bloom's Revised Taxonomy

Bloom, Engelhart, Furst, Hill and Krathwohl [13] developed the Taxonomy of Educational Objectives - to classify cognitive learning processes. It was revised by Anderson and Krathwohl [14] to reflect 21st-century educational needs, and is now referred to as BRT, structured around two dimensions, namely Knowledge (factual, conceptual, procedural, and metacognitive) and Cognitive Processes (remember, understand, apply, analyse, evaluate, and create).

The study used BRT to analyse the current and potential future scenario; of the six levels of cognitive learning, only the ethics component requires students to apply their knowledge, while the remaining learning outcomes are primarily focused on recall (remember), with some level of understanding included (understand). The Knowledge Dimension is also considered, including factual, conceptual, procedural, and metacognitive knowledge.

3 Research Design

This study adopts a conceptual design-oriented research approach – it is (1) contextualised and informed by the authors' specific institutional and student context as a way to ensure feasibility and therefore analyses the current course outcomes to enable outcome supporting suggestions. Then (2) BRT acts as a theoretical lens to integrate the structured set of practical learning interventions aligned with these outcomes. This research is conceptual and theory-driven rather than empirical; it does not examine student performance, which is a foreseeable future endeavour, but proposes an amended module offering. The purpose is to encourage a deeper understanding of security concepts and allow for its integration into computing processes.

4 Contextual Analysis

The Nort-West University has four campuses, one online campus and three physical campuses. All campuses, except for one physical campus offer the module under discussion. In all cases practical laboratories are not available immediately. In this context, document analysis is suitable to amend learning outcomes (LOs) and assessment criteria (ACs), with a variety of practical

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opportunities [15]. It functions as the primary category of data sourcing from existing literature, and in the form of the module's LOs, as the learning contract between lecturer and student [16]. The current context of the subject module is an 8-credit 2nd-year single semester theory-based offering.
Table **2** relays the module's LOs, which aligns with ACs, addressing the categories of knowledge, methods and procedures, as well as ethics and professional practice.

Table 2. Information Security module outcomes

Learning outcomes	Category	Assessment criteria
After the successful completion of this module, the student must be able to demonstrate:		You have reached the outcomes if you are able to:
LO1: On theoretical level the student should have insight and basic knowledge of main concepts of information and cyber security. These include concepts such as confidentiality, integrity, availability, authentication, privacy, secure software development, backup and recovery, legal and ethical issues. LO2: The student is introduced to security threats in the world we live in and should be able to recognise appropriate controls to counteract these threats.	Knowledge	AC1: List, identify and discuss the main concepts of information and cyber security. These include concepts such as confidentiality, integrity, availability, authentication, privacy, secure software development, backup and recovery, legal and ethical issues. AC2: Identify and describe security threats in the world we live in and to recognise and propose appropriate controls to counteract these threats.
LO3: The students should have the ability to identify and have knowledge about security threats and vulnerabilities in a computerised environment such as hardware errors, software failures, human errors, malicious intent and natural causes. LO4: The students should demonstrate that they have knowledge and can identify applicable controls and countermeasures on different levels such as technical controls, physical controls, and procedural controls as well as social controls to counteract the security threats and vulnerabilities in a computerised system.	Methods & procedures	AC3: Identify, discuss and understand security threats and vulnerabilities in a computerised environment such as hardware errors, software failures, human errors, malicious intent and natural causes.
LO5: The students should have the ability to act according to the code of conduct of the IT profession towards clients and to use computer resources ethically and responsibly.	Ethics & professional practice	AC4: Act according to the code of conduct of the IT profession towards clients and to use computer resources ethically and responsibly.

As was relayed earlier, the material is presented predominantly from a theoretical perspective, resulting in a knowledge-focused learning experience. Students often find it difficult to visualise how theoretical concepts manifest in practice, and important concepts within this critical subject may be perceived as abstract, with limited connection to real-world threats that need to be addressed.

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5 Theory to Practice Possibilities

This section presents the components necessary for introducing applied security thinking within the Information Security module. The aim of this discussion is not to transform the module into a technical cybersecurity laboratory, but rather to introduce practical engagement opportunities that reinforce theoretical concepts through applied reasoning and student participation. The discussion focuses on a series of complementary interventions that can be implemented within existing curriculum constraints. These interventions aim to create opportunities for students to encounter security considerations during normal learning activities rather than through specialised or advanced technical exercises. The design emphasises feasibility, ensuring that the proposed activities can be integrated into a 2nd-year module without requiring additional infrastructure, learning new programming languages, or setting up a specialised security laboratory.

5.1 Flipped Classroom Participation

To promote active engagement during teaching sessions, elements of a flipped classroom approach may be incorporated into the module, where students are expected to come prepared to contribute beyond the basic material provided. These contributions may carry small participation marks. Two interventions are proposed, namely short presentations and micro practical activities.

Short Presentations. Students may be invited to prepare short presentations on selected security topics throughout the semester to encourage active participation and critical thinking. These may include explanations of security concepts, summaries of recent cybersecurity incidents, or discussions of relevant practices. For example, small groups may present foundational cryptography concepts, such as demonstrating how a Caesar cipher operates. Such activities stimulate class discussion and create an interactive learning environment.

Micro Practical Activities. A series of short, focused practical exercises may be distributed throughout the semester and integrated into normal teaching sessions without requiring specialised infrastructure.

For example, each activity may target a specific concept that requires students to apply theoretical knowledge in simplified contexts, where short coding tasks, the analysis of insecure code, the evaluation of password policies, or identifying vulnerabilities are required. These practical activities may also be linked to presentations. As an example, students may implement a Caesar cipher using simple Python scripts to demonstrate encryption and decryption, allowing peers to test the cipher and identify weaknesses.

The exercises are intentionally lightweight and do not aim to replicate full cybersecurity laboratories. Instead, they provide repeated exposure to practical scenarios, helping students recognise how security considerations arise in everyday computing tasks. Their flexibility as in-class activities, homework, or

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discussion-based exercises makes them suitable for second-year students without requiring advanced technical skills.

5.2 Game-based Learning

Game-based learning activities may also be incorporated into the module to introduce security concepts in a more interactive and engaging manner.

An example is the use of the Cyber Threat Defender (CTD) card game [17], which is designed to simulate cybersecurity decision-making in an accessible and collaborative format. During the activity, students work in small groups and assume the role of defenders responsible for protecting organisational assets from cyber threats. The game introduces students to common security concepts such as threat identification, vulnerability management, risk mitigation, and defence strategies. Each round requires players to analyse potential attack scenarios and select appropriate defensive actions using the cards available to them. Through this process, students are exposed to the strategic thinking required when prioritising security controls in a constrained environment.

The use of such games allows students to experience cybersecurity challenges in a low-pressure setting where discussion and experimentation are encouraged. Students often debate which defensive strategies may be most effective, prompting reflection on the theoretical concepts introduced during lectures. In this way, the activity reinforces security principles while also promoting collaboration among students when solving problems.

5.3 Guided Challenge Activities

To further support applied learning, guided challenge activities using structured cybersecurity platforms such as TryHackMe, may be incorporated. These platforms provide step-by-step exercises in which students interact with controlled virtual environments and are guided through structured tasks and questions. Through these scaffolded activities, students are introduced to security concepts, they observe system behaviour and develop an understanding of vulnerabilities and their mitigation without requiring independent exploitation.

Within the module, such activities would be used selectively to reinforce theoretical topics covered during lectures. They provide exploratory learning opportunities where students can observe security mechanisms in practice and reflect on how vulnerabilities may arise during software development, while maintaining an appropriate defensive focus for an introductory course.

For example, students may complete introductory tasks within pathways such as “Pre-Security” or “Introduction to Cyber Security,” engaging with guided exercises on topics such as authentication, password strength, and common vulnerabilities. A typical activity may involve analysing weak passwords using dictionary-based approaches, allowing students to understand why vulnerabilities occur and how stronger controls can mitigate them. Students may also be encouraged to continue progressing through these pathways outside of

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class time, enabling further practical exposure while ensuring that the core classroom activities remain accessible to all learners.

5.4 Integrated Cross-Module Project

A central element of the proposed approach is a collaborative project spanning multiple second-year modules, such as Programming, Information Security, Systems Analysis & Design (SA&D), and Communication Skills. The purpose is to expose students to the interdisciplinary nature of secure software development. In professional environments, security is rarely confined to a single role or discipline. Instead, secure systems emerge through collaboration between software developers, security practitioners, and individuals responsible for communicating design decisions and associated risks.

For example, student groups may develop a software application within the SA&D and Programming modules while applying standard systems development practices. The application need not be technically complex but should include features such as user authentication, password management, input handling, or data storage to facilitate discussion of security considerations. The Information Security module may require students to evaluate the security implications of their implementation choices, including authentication, access control, input validation, and potential vulnerabilities. The Communication Skills module may further support the project by requiring students to justify and communicate their security decisions through reports or presentations. Such integrated projects reinforce the view that security is not an isolated theoretical topic but a design consideration embedded throughout the systems development lifecycle, helping students develop an applied appreciation of security as a normal part of computing practice.

5.5 Optional Participation in Challenges

Students interested in gaining additional practical exposure may be encouraged to participate in cybersecurity challenges outside the semester in which the Information Security module is offered. Participation is voluntary and does not form part of formal assessment. Students who choose to participate can explore challenge environments independently, gaining exposure to practical problem-solving and a range of cybersecurity tasks, thereby extending learning beyond the classroom.

One example is the South African National Research Network (SaNReN) Cyber Security Challenge (CSC), a capture-the-flag (CTF)-style competition designed to introduce students to practical cybersecurity problem-solving through progressively challenging tasks. Participants engage with domains such as cryptography, digital forensics, web security, and network analysis [18], working through exercises that simulate realistic scenarios, including analysing outputs, identifying vulnerabilities, and decoding information. These challenges emphasise exploration and learning rather than formal assessment.

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Encouraging participation in the SaNReN CSC provides motivated students with an opportunity to deepen their practical understanding while at the same time, engaging with the broader cybersecurity community. As an optional activity, it supports extended learning without compromising the accessibility of the core module.

5.6 Implementation of the Elements Suggested

Through student presentations, micro-activities, scenario discussions, integrated projects, guided challenges, and optional external competitions, the module seeks to shift the learning experience from purely theoretical understanding toward a more applied appreciation of security considerations within computing practice. Collectively, these interventions aim to introduce applied security thinking within the Information Security module while remaining feasible within the constraints of a 2nd-year curriculum. Rather than relying on advanced technical laboratories or offensive security exposure, the proposed design emphasises repeated exposure to security decision-making during normal learning activities. Care should be taken that the integration of these suggested interventions is done in such a way that it supports student learning while not being repetitive or overwhelming.

6 Learning Outcomes meet Bloom's Revised Taxonomy

To assess the educational alignment and potential cognitive progression introduced by the proposed model, BRT mapping was used as a proxy evaluation approach. Since the model has not yet undergone full classroom implementation, the mapping serves to evaluate whether the proposed interventions support progression from lower-order theoretical understanding towards higher-order applied and analytical security thinking.

The mapping of LOs against BRT was conducted to reflect the module's existing theoretical orientation, as well as the potential cognitive progression anticipated following implementation of the proposed model.

Currently the following analyses reflects the learning expected; LO1 – factual; remember, LO2-LO3-LO4 – factual; understand, and LO5 – conceptual; apply | procedural; analyse.

In Table 3 the proposed practical interventions are aligned with the existing module learning outcomes to ensure that applied activities support, rather than replace, the intended theoretical objectives. The interventions are further mapped to BRT to demonstrate progression from lower-order cognitive processes (remember, understand) towards higher-order processes (apply, analyse, evaluate), with an increased emphasis on procedural and metacognitive knowledge, as opposed to factual and conceptual knowledge.

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Table 3. Alignment of practical interventions with existing LOs

Practical Intervention	Rationale	Learning Outcome Supported	Original Bloom Mapping	Envisaged Bloom Mapping
Flipped Classroom	Student presentations reinforce conceptual understanding of security principles	LO1	factual; remember	conceptual; understand
	while encouraging discussion and interpretation of security threats	LO3	factual; understand	conceptual; apply
	The requirement to explain and justify concepts also promotes ethical awareness and responsible communication	LO5	conceptual; apply | procedural; analyse	conceptual; analyse
Micro Practical Activities	Short, applied tasks allow students to move beyond theoretical understanding	LO1	factual; remember	procedural; apply
	Short, applied tasks allow students to move beyond theoretical understanding	LO2	factual; understand	procedural; apply
	while also identifying vulnerabilities and interpreting their impact	LO3	factual; understand	procedural; analyse
Game-Based Learning	Game-based scenarios require students to recognise threats and select appropriate controls	LO2	factual; understand	procedural; apply
	analyse vulnerabilities and risks	LO3	factual; understand	procedural; analyse
	consider the effectiveness of different defensive strategies	LO4	f actual; understand	procedural; analyse
Integrated Cross-Module Project	The project requires students to identify threats and propose controls	LO2	factual; understand	procedural; apply
	analyse vulnerabilities within their own systems	LO3	factual; understand	procedural; analyse
	apply appropriate security measures	LO4	factual; understand	procedural; evaluate
	and justify decisions in an ethical and professional manner	LO5	conceptual; apply | procedural; analyse	metacognitive; create
Guided Challenge Activities (TryHackMe)	Structured challenge environments reinforce theoretical concepts	LO1	factual; remember	conceptual; understand
	expose students to real-world security threats	LO2	factual; understand	procedural; apply
	and allow them to analyse how vulnerabilities manifest in practice	LO3	factual; understand	procedural; analyse
Optional Participation (SaNReN CSC)	Participation in CTF-style challenges exposes students to practical problem-solving where they identify threats	LO2	factual; understand	procedural; apply
	analyse vulnerabilities	LO3	factual; understand	procedural; analyse
	and apply security concepts in more complex contexts	LO4	factual; understand	procedural; evaluate

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Following the inclusion of these interventions, more of the learning outcomes are supported at higher cognitive levels, particularly in terms of application, analysis, and evaluation. This shift reflects a transition from a predominantly knowledge-based learning experience towards one that encourages applied security thinking within the constraints of a 2nd-year module.

7 Proposed Practical Intervention Model

The proposed model conceptualises the introduction of applied security thinking as a structured, layered process consisting of interrelated components that progressively develop student capability. The model is organised into three layers, the conceptual foundation, scaffolded application, and an optional extension; each serving a distinct pedagogical function while remaining aligned with BRT.

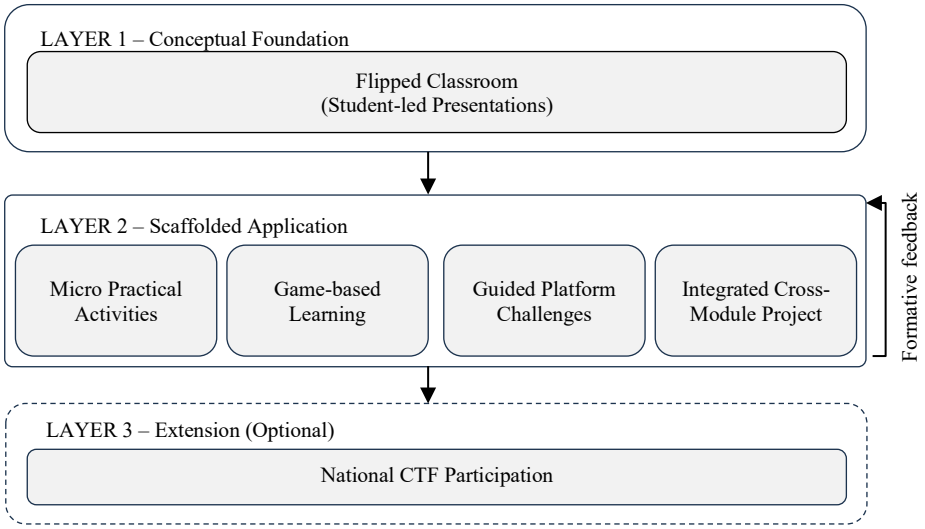
Layer 1 establishes the conceptual foundation through a flipped classroom approach, as illustrated at the top of **Error! Reference source not found.**. This layer is intentionally positioned as a prerequisite, indicating that all subsequent engagement is dependent on a baseline level of conceptual understanding. Through student-led presentations, in-class engagement, and structured concept discussions, students actively construct foundational knowledge rather than passively receiving it. The visual encapsulation of this layer as a single, bounded component reflects its role as a unified entry point into the model, ensuring that students are adequately prepared before progressing to more applied activities.

Layer 2 forms the core of the model and represents scaffolded application, with the horizontal layout in the figure explicitly depicting the increase in cognitive demand from left to right. Within this layer, students engage with a sequence of complementary activities, namely micro practical activities, game-based learning, guided platform challenges, and an integrated cross-module project. The positioning of these components is deliberate: micro practical activities provide an accessible entry into applied thinking through small, structured tasks, while game-based learning introduces decision-making in a low-risk, interactive context. Guided platform challenges, such as structured TryHackMe pathways, extend this engagement into more realistic environments where students encounter controlled representations of security scenarios. The integrated cross-module project is positioned at the far right of the layer to reflect its role as the culminating activity, requiring students to synthesise knowledge, apply security principles within a development context, and justify decisions in a coherent and integrated manner.

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Fig. 1. Information Security Practical Intervention Model



Importantly, the figure conveys that progression within Layer 2 is not strictly linear. While the left-to-right arrangement indicates increasing complexity, the absence of rigid sequencing and the presence of feedback loops emphasise that students may move iteratively between activities. This allows concepts introduced in earlier stages to be revisited and reinforced as students engage with more complex tasks. The model therefore supports a cyclical learning process, where understanding is continuously refined through repeated exposure to applied contexts.

The vertical alignment between Layer 1 and Layer 2 further illustrates the dependency between conceptual understanding and applied engagement. The downward transition shown in Fig. 1. Information Security Practical Intervention Model

signifies that foundational knowledge directly informs the way students approach practical tasks. In turn, the experiences gained in Layer 2 reinforce and deepen conceptual understanding, creating a bidirectional relationship between theory and practice.

Layer 3, depicted as a separate and visually distinct component, provides an optional extension through participation in a national cybersecurity challenge, such as the South African National Research Network (SaNReN) Cyber Security Challenge. The dashed boundary used in the figure communicates its optional and self-directed nature, distinguishing it from the core module activities. This layer enables motivated students to extend their learning into less structured and more complex environments, while ensuring that the core model remains accessible to all students regardless of prior experience or interest level.

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A defining characteristic of the model, as reflected in the figure, is its feasibility within constrained educational environments. The components are designed to be lightweight, modular, and adaptable, requiring no specialised infrastructure or additional curricular restructuring. This makes the model suitable for large classes and introductory-level students, while still enabling meaningful engagement with applied security concepts. The visual simplicity of the model reinforces this principle, presenting a structure that can be realistically implemented within existing teaching contexts.

Furthermore, the model responds to the broader curricular context in which the Information Security module is situated. As the only dedicated security-focused module within the BSc Information Technology programme of the authors' context, with continuation only at Honours level, there exists a gap in sustained engagement with security topics. The inclusion of the optional extension layer provides a mechanism to bridge this gap, offering interested students an avenue for continued development beyond the confines of the module. In this way, the model not only enhances learning within the module itself, but also supports longer-term engagement with the cybersecurity discipline.

8 Conclusion

This paper proposes an Information Security Practical Intervention Model to enhance a predominantly theoretical Information Security module through the inclusion of practical applications. The suggested interventions are intentionally non-invasive, require only basic tools, and are suitable for large class sizes. The model is also adaptable to alternative contexts where students have prior security knowledge, supporting infrastructure is available, or smaller class groups permit more intensive engagement.

The study demonstrates that applied security thinking can be integrated into theoretical Information Security modules through a layered intervention model combining micro-practical activities, reflective exercises, and gamified learning without requiring substantial curricular restructuring. By aligning practical interventions with existing learning outcomes, the model provides a feasible and transferable approach for introducing practice into theory-driven modules without specialised laboratories, additional resources, or offensive security activities.

This study is not without limitations. The proposed model is conceptual and has not yet been empirically evaluated within a live teaching environment. Consequently, its effectiveness in improving student engagement, learning outcomes, and applied security thinking remains untested. Furthermore, the model was developed within a specific institutional and curricular context, which may influence its applicability elsewhere.

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Future work will involve a Design-Based Research implementation in which selected interventions are introduced, evaluated, and refined through iterative cycles.

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Designing Immersive Virtual Reality Learning Environments for Software Engineering: A Reflective Study

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Abstract. The acceleration of online learning over the years has reshaped how higher education institutions adopt technology tools to deliver technically demanding courses, such as Software Engineering, in remote learning contexts. While higher education institutions provide opportunities for self-development, working students often face challenges relating the theory of Software Engineering to real-world practice. While online learning platforms such as Learning Management Systems (LMS's) offer flexibility and accessibility to course delivery, higher education institutions need to incorporate strategies to motivate students, enhance their understanding of abstract concepts in course material, and maintain student engagement while improving academic progress. Immersive virtual reality (VR) online platforms provide students with opportunities to experience innovative learning of abstract core concepts through active engagement within virtual reality learning environments (VRLE's). VRLEs are virtual 3D worlds designed to enhance student understanding by allowing them to interact with embedded course material in an immersive, simulated real-world environment. This study documents the development of a VRLE as a cost-effective immersive technology solution to support the learning of content material in a Software Engineering course for fourth-year students at a South African distance-learning university. The VRLE was designed in alignment with the Virtual Reality Mathematics Teaching Integration (VRMTI) Framework, which was applied within the Software Engineering context. The study contributes practice-based knowledge drawn from the initial implementation of the VRMTI framework.

Keywords: Virtual reality, learning environments, Software Engineering, online education

1 Introduction

Virtual Reality (VR) technology has been increasingly adopted in higher education due to its potential to shape how students perceive learning core concepts when immersed in 3D worlds [1]. In fields such as Software Engineering, where conceptual understanding and practical skills are essential, students who are working and studying online often face challenges in managing their studies alongside personal and

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professional commitments [2]. Working students can overcome challenges through online learning enabled by technology, such as Learning Management Systems (LMSs), which offer options for when and how students learn (synchronous or asynchronous) [2].

Whilst LMS's provides substantial content-related support to facilitate online learning, innovative technologies such as VR used for educational purposes can provide opportunities to transform learning environments into immersive spaces where students can actively engage with and deepen their understanding of fundamental concepts [3].

To complement the facilitation of online learning space through LMS's, virtual reality learning environments (VRLE's) situate students within interactive, three-dimensional simulations where abstract concepts can be visualised, manipulated, and explored [4]. VRLE's are three-dimensional virtual platforms with virtual objects [5], that create opportunities for educators to present the learning of fundamental concepts, typically included in Software Engineering courses, in an exciting and innovative way, while improving spatial learning and knowledge retention [6]. For this reason, the authors developed a VRLE using the cost-effective web-based VR technology, namely Delightex. Based on the principles of the Virtual Reality Mathematics Teaching Integration (VRMTI) Framework, a trial prototype solution was developed focusing on the content of a fourth-year Software Engineering module. The objective of this study is to reflect on the development and implementation of the prototype from a development perspective. Although future research will explore student feedback, this was not an objective of this study.

The outline of the paper is as follows: a literature review explores VRLE software and web-based platforms; theoretical foundations for technological teaching and learning; and learning theories, teaching strategies, and pedagogical approaches. The research approach section discusses the three-phase approach used for the design and implementation of a Software Engineering VRLE. The conclusion and future work conclude the paper.

2 Literature Overview

Software Engineering refers to an engineering-based, systematic approach used to design, develop, test, deploy, and maintain software systems [7]. Although it is often confused with producing programming code, the concept focuses on the entire software development lifecycle, which ultimately aims to produce high-quality, maintainable software whilst meeting the original objective of the software development stakeholders. To master these concepts, researchers have identified both situational and learning challenges. Situational challenges are challenges students encounter in their specific context. For example, it is often difficult for students to imagine the requirements analysis phase of Software Engineering, where analysts actively engage with stakeholders to gather their requirements. Learning challenges, on the other hand, refer to challenges related to engaging with Software Engineering theoretical constructs – how curriculum content relates to practice in industry [8, 9]. To bridge the gap between theory and practice in Software Engineering education, educators and content creators need to

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employ innovative pedagogical approaches that actively engage students in learning experiences [8]. Authors recommend that educators employ technology with an emphasis on gamification, to improve students learning experience [10]. Embedding gamification within VR learning environments motivates students to enhance understanding through learning that is perceived as meaningful [1]. A discussion on VRLE and Web-based platforms follows.

2.1 VRLE Software and Web-based platforms

The utilization of software and web-based platforms in VRLE is nothing new. For example, 3D modeling engines such as Autodesk, REVIT, and Unity have been used extensively to build 3D objects for VRLE's [11]. Frame VR is an example of a web browser-enabled platform that allows users to purchase subscriptions and design their own immersive VRLE's [12]. From a design perspective, creating VRLEs requires additional design capability subscriptions and the option to attend training on using, creating, and customizing VRLE learning platforms. The level of complexity to build VRLEs and the level of immersion each platform offers vary and can be complemented with the use of VR headsets such as the MetaQuest range (Quest 2 and Quest 3), HTC Vive, and Vision Pro, among others. Furthermore, there are cost implications based on the selection of VR software platforms and hardware that users decide to invest in. For example, VR software creation platforms that offer more features, such as multi-user environments that support social interaction (social VR) and can be used as a meeting platform, cost more than platforms with fewer features. Delightex, a web-based VR creation tool with a block-based coding interface, is a cost-effective, user-friendly solution for creating VRLEs [13]. With cost-effectiveness and ease of use as the main criteria, Delightex was the preferred VR tool for creating the Software Engineering VRLE. For example, Delightex includes a drag-and-drop toolkit with a library of 3D objects and characters, building structures, and 3D environments.

2.2 Theoretical Foundations for Technological Teaching and Learning

Technology integration models are theoretical frameworks that guide educators and stakeholders in integrating technology for effective teaching [14]. To guide the implementation of VR in educational environments, a framework was developed with the main objective of supporting mathematics educators in integrating VR into mathematics teaching. The framework, referred to as the VRMTI Framework, was based on two theories: Technology, Pedagogy, and Content Knowledge (TPACK) and Substitution, Augmentation, Modification, and Redefinition (SAMR). The SAMR model helps educators distinguish how the technology will be integrated and at which level, namely Substitution, Augmentation, Modification, or Redefinition [15]. For example, educators can decide whether the VRLE poster is a virtual representation of the physical classroom poster (substitution) or provides real-time feedback when a quiz is activated by clicking a 3D object in the virtual environment (augmentation). Furthermore, TPACK was used to guide educators in selecting VR technology, content, and teaching methods or approaches for lesson planning, preparation, and delivery, and SAMR was

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used to determine how VR technology would enhance learning. Although the original objective of the framework was to guide mathematical educators, the framework could easily be adapted for other, similar environments. For example, both the mathematical and Software Engineering environments contain strong elements of theoretical construct understanding combined with practical application. The methodology section of the paper discusses how the VRMTI Framework Component – VR Lesson Integration Guide was adapted to cater to Software Engineering educational environments to alleviate students' learning challenges. This seemed applicable as both subject areas were part of Science, Technology, Engineering, and Mathematics (STEM) education.

2.3 Learning Theories, Teaching Strategies, and Pedagogical Approaches

Prior research has indicated that constructivist, experiential, and active learning teaching strategies can be used to teach fundamental Software Engineering concepts using VR technology [1]. This is due to the ability to design VRLE's to include interactive tasks for students that support constructivist learning [16], by encouraging students to build on previously acquired knowledge [17]. These tasks may include investigating challenges involving content and drawing conclusions or solving problems, which improves understanding and consolidation of learning [18].

VRLE's can be designed to include activities that require students' active participation and hands-on engagement, thereby fostering students' practical and cognitive skills [19]. This active and hands-on engagement embodies experiential learning [20], which guides how VR can be implemented [16] to improve how students learn and comprehend [20]. Creators of VRLEs, in this case for Software Engineering, can design 3D learning spaces that incorporate constructivist, experiential, and active learning theories to optimize students' learning potential.

Pedagogical approaches compatible with VR technologies can be used alongside learning theories to enhance students' understanding of concepts [21]. These include scaffolding, inquiry-based learning, game-based learning, problem-solving, and project-based learning. **Table 1** summarizes the teaching methods and approaches used by VR lesson creators, along with the objectives for their use. This can be used by designers to select appropriate content for incorporation into immersive spaces to enhance students' understanding.

Table 1. Teaching approaches and methods

Teaching Approach(es)/Method(s)	Objective in using the approach	Reference
Scaffolding, Collaborative	Increase motivation and academic achievement	[22] [23] [24]
Inquiry-based	Improve students' knowledge, interest, and self-efficacy.	[25]
Game-based learning and problem-solving	Achieve positive learning outcomes and improve learning achievement and satisfaction.	[26] [27] [28]
Game-based learning and Constructivism	Enhance learning, motivation, and engagement with STEM	[29]

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3 Research Approach

The VRMTI Framework was developed using the Design Science Research (DSR) methodological approach. DSR is particularly suitable in instances where an artifact, which can be a model or framework, is developed to solve a real-world problem [30]. As part of the VRMTI Framework, a VR mathematics lesson integration guide was developed through a systematic literature review. This was part of the first iteration of the framework, developed as a PhD study due to limited guidance in literature on VR integration into teaching [6] and although the focus was on mathematics teaching, it was adapted to design the Software Engineering VRLE. Section 3.1.3 provides a further discussion on the adjustments made.

3.1 Design and Implementation of the Software Engineering VRLE

The design and implementation of the Software Engineering VRLE consisted of three phases, namely: (1) preliminary preparation phase; (2) design of digital resources and VRLE; (3) VRMTI framework component and VR lesson integration guide.

3.1.1 Preliminary preparation phase

As a preliminary process to prepare for the implementation of the VRLE with students in the Software Engineering course, the researcher met with the Software Engineering course lecturer in a series of Microsoft Teams meetings, commencing in May 2025. During these meetings, the information and discussions focused on obtaining relevant module information, content, and learning outcomes; preparing VR digital resources; pretesting VRLE; the implementation process and scheduling; VR technology selection; software licensing and subscription; teaching resources; and training on the integration process during implementation. A Microsoft Teams site was created, where all relevant content was shared, including course materials such as journal articles for each of six units that students needed to read and synthesise (in the absence of a prescribed textbook). All teaching resources were created by the researcher in collaboration with the lecturer, given the researcher's proficiency in using the software to develop the Virtual Reality Learning Environment (VRLE) and digital resources. The VRMTI framework integration guide was adapted and followed in the creation of all VR resources (see section 3.1.2 and 3.1.3 for more information).

Gaining access to Delightex, the software application selected to create the VRLE, was an essential part of the preliminary phase. The Delightex web environment was subscription-based for Pro users and free for Basic users. Since the Basic license provided access to limited features, the researcher purchased a Pro license and required licenses for the lecturer and students as users of the VRLE. The Software Engineering class consisted of 564 students, each of whom needed a license to trial the VRLE. To accommodate all users, the researcher created two Gmail addresses, each signed up for a Delightex Pro Trial license with 100 seats, valid for 45 days. To accommodate all students, an Excel workbook was created to record 6 groups (5 groups x 100 students and 1 group for 64), with each group allocated approximately 15 days to work within

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the immersive environment. The researcher's license was purchased to enable the creation of the VRLE, and trial licenses were secured only closer to the intended implementation period.

3.1.2 Design of digital resources and VRLE

Designing the VRLE for the Software Engineering module required designing it as a shell as the first step, creating digital resources as the second, and embedding them in the VRLE shell as the third. The TPACK model was used to design digital resources and VRLE by combining appropriate pedagogies with Software Engineering content and technologies to create opportunities for students to consolidate concepts.

The VRLE was created using the Delightex web application as a shell. Delightex has a gallery feature that allows designers of VRLEs to remix an existing environment or create a new one. To create the Software Engineering VRLE, an existing environment was remixed, specific walls were removed to create an open environment, and other walls were repositioned with Delightex's creation toolbox.

Appropriate furniture, LED screens, props, plants, other décor, and information boards were added to the environment, as displayed in **Fig 1**.

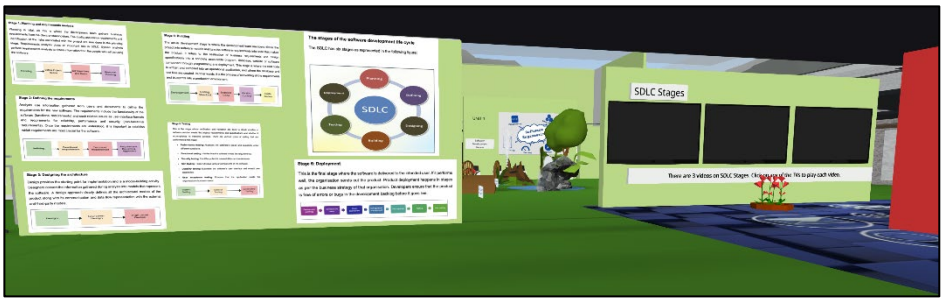


Fig 1. VRLE environment containing posters, wall mounted LED screens and other décor objects

Coding tools within the Delightex environment allow the user to initiate tasks, for example, websites are linked to objects in the VRLE. When the user clicks the LED screen, the video starts playing. **Fig. 2** displays the Delightex Coding tool options used to initiate action.

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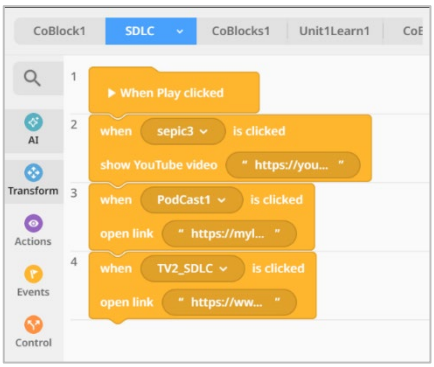


Fig 2. Delightex Coding tool options used to initiate action

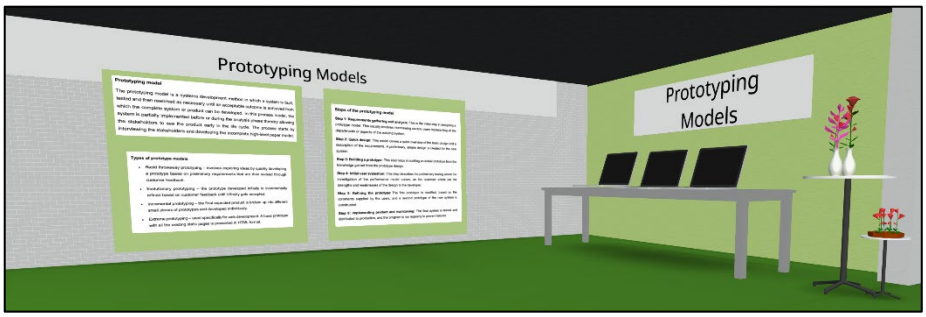


Fig 3. Laptops that initiate quizzes when clicked.

Fig 3 displays laptops as 3D objects in the VRLE, which, when clicked, launch a quiz for students to answer. Quizzes can be initiated in the VRLE when the user clicks on the links attached to the laptop object. The quiz, created in the institutional LMS, can be initiated through the link in the VRLE. The LMS and VRLE's can be linked through this design feature. Incorporating quizzes in a VRLE represents technology use at the Augmentation level of the SAMR model. The use of posters that users read for information and to gain understanding represents the Substitution level of SAMR's model, as the poster in the virtual environment is a digital representation of the poster in a physical classroom.

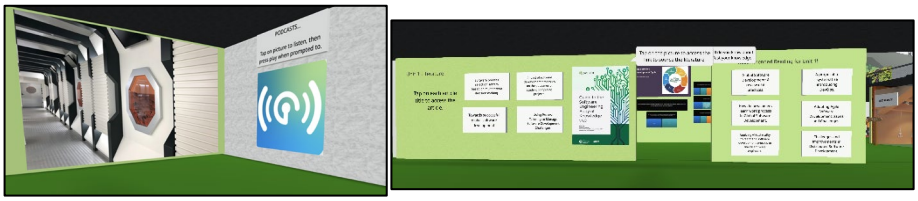


Fig 4. Scene from VRLE with a podcast and links to recommended journal articles

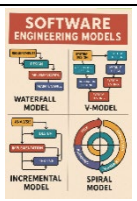
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Among the variety of digital resources used in the VRLE, podcasts were generated from journal articles through one of Notebook LM's features. Students were able to click the podcast picture (shown in the left scene of **Fig 4)** to listen to an Artificial Intelligence (AI) - generated podcast that provided a summary of the article as a conversation between two people. Introducing the podcast as a resource is an example of the Modification level of SAMR's model, as the article was transformed into a synthesis through the podcast. The posters displayed on the scene positioned on the right in **Fig 4** link to the article source for the recommended reading list for Unit 1. Students enhance their learning of Software Engineering concepts through reading literature. The technology represented here is at the Augmentation level of the SAMR model.

Digital resources (information posters, Kahoot quizzes, a wordsearch activity, YouTube videos, links to journal articles, and the Notebook LM podcast) were created from content provided by the Software Engineering lecturer prior to the design of the Software Engineering VRLE. **Table 2** displays the digital resources that were created for the Software Engineering VRLE - Unit 1.

Table 2. Digital Resources designed for Software Engineering VRLE

#	UNIT 1 Resources	Task Objectives	Resource examples
1	Poster – Software Engineering Models	Identify Software Engineering Models	
2	SDLC Wordsearch	Identify Software Engineering concepts based on given clues.	
3	SDLC Kahoot Quiz - Example	Questions on SDLC	
4	YouTube video on Software Development Process	Learning about the Software Development Process	
5	Notebook LM Podcast created from an uploaded article	What is Global Software Development?	

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6	Links to Unit 1 recommended reading list	Read articles from recommended reading list to consolidate understanding of Unit 1 objectives.	

3.1.3 VRMTI framework component and VR lesson integration guide

The VR mathematics integration guide, a component of the VRMTI Framework, was created for VR-integrated mathematics lessons that blended a physical lesson with a VRLE. Since the Software Engineering lesson was online, the VRMTI lesson Integration Guide was adapted to create a VRLE for the distance-learning Software Engineering course. Steps that were not relevant to the adapted model were removed. **Fig. 5** presents the adaptation of the integration guide for the Software Engineering VRLE.

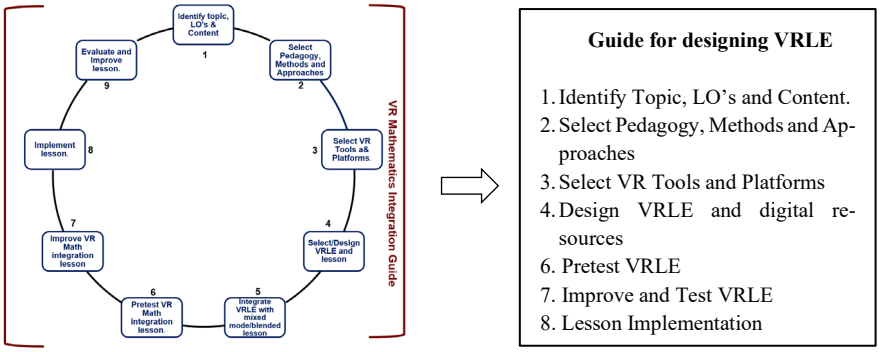


Fig 5. VRMTI – VR lesson Integration Guide adapted for Software Engineering VRLE

An explanation of the steps in the adapted VR integration guide (renumbered) that was used to create the VRLE for the Software Engineering module follows.

Step 1: Identify Topic, Learning Outcomes, and Content – Unit 1 module information and content supplied by the Software Engineering lecturer were used to identify the topics, learning outcomes, and content in the creation of VR digital resources.

Step 2: Select Pedagogy, Methods, and Approaches – A range of pedagogical approaches is available for designers to incorporate into VR lessons. Some examples include inquiry-based, project-based, and problem-based learning, as well as collaborative and active learning approaches. The inquiry-based approach promotes exploration, problem-solving, and critical thinking [25, 31, 32]. Incorporating the inquiry-based approach provided opportunities for students to navigate the Software Engineering VRLE using phone, iPad, or arrow keys on the keyboard to move around the VRLE, watch videos (embedded on virtual laptops or screens), consolidate learning through finding information on posters and information boards, and use this knowledge to answer quizzes, wordsearches and VRLE links to tasks created on the LMS.

Step 3: Select VR Tools and Platforms – The selection of VR tools (Delightex web-based software, phones, iPads, or computers) was based on what was easily accessible

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and available as a lower-cost option. The VRLE can be used with or without immersive headsets.

Step 4: Design VRLE and digital resources – The process of designing these resources was discussed earlier in this section.

Step 5: Pretest VRLE – Both the researcher and lecturer pretested the Software Engineering VRLE multiple times.

Step 6: Improve and Test VRLE - Improvements were made to ensure that there were no problems. This was followed by repeated testing and improvement until both the researcher and lecturer were satisfied that the VRLE was ready for implementation.

Step 7: Lesson Implementation – Prior to lesson implementation, the researcher and lecturer divided the student class list into six groups based on student email addresses. Each of the two groups (simultaneously from two different email addresses) were given access to the VRLE for approximately 15 days each. This process was repeated for the next two groups until all groups received access and the remainder of the trial membership had expired. Following this, the lecturer scheduled a Microsoft Teams meeting with students during which time students were briefed on the following – the process to follow when a link to the Software Engineering VRLE was sent to them, how to install the Delightex Application, and how to access and navigate the VRLE. The URL and share code (displayed in **Fig 6.**) of the Software Engineering VRLE was distributed to students via email to each group a day before the access was allowed with instructions on the trial period that was allocated. Students were notified that support would be provided by both the researcher and lecturer should they have any questions during the trial period.

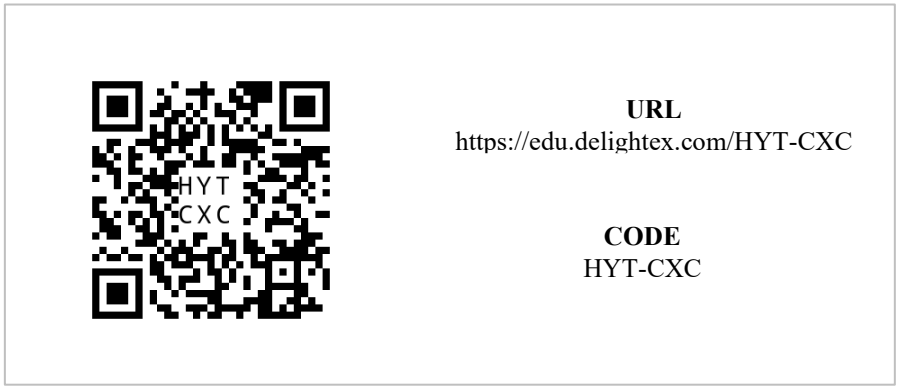


Fig 6. QR Code, Link and Share Code for the Software Engineering VRLE

4 Reflection

The development of the immersive Software Engineering VRLE represents an implementation strategy on how distance education can actively engage students to enhance understanding concepts that are usually perceived as abstract and complex. The adaptation of the VRMTI Framework originally designed for Mathematics education

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to suit the needs of a Software Engineering module is evidence of the flexibility of the framework to be adapted to other disciplines. Additionally, immersive technologies are flexible, creative, innovative technology tools that have the potential to create relevant, meaningful, interactive experiences.

Reflecting on the design process, it is clear that a systematic approach needs to be followed in the creation of the Software Engineering VRLE, which needs to be carefully planned to incorporate – the learning outcomes, innovative pedagogies and learning theories and relevant content. To achieve the intended learning outcomes, the VRLE needs to be designed to simulate real world environments that captivate and actively engage students in meaningful learning. Designing the digital resources that are embedded within the VRLE is time consuming and requires patience, time for planning and collaboration with other educators. Creators of VRLE's have many design options or forms (virtual labs, scavenger hunts, virtual trips, virtual games or quests among others) that virtual learning environments can take. Since there are limited subject specific VRLE's available, creating and sharing platform specific digital teaching resources with other educators with similar access within the university will save time and effort.

Delightex is a user friendly, low cost, web-based platform that has a library, toolbox and code features used for designing VRLE's as functional learning environments.
Reflecting on the design process, it is clear that the systematic approach taken, beginning with the clear identification of learning outcomes and relevant content, followed by the selection of appropriate pedagogies, established a solid foundation for VRLE development. The incorporation of inquiry-based learning methods within the VRLE, allowing students to actively explore, problem-solve, and critically engage with abstract Software Engineering concepts, leverages well-established active learning theories. Educators have a wide variety of teaching approaches to choose from when deciding on activities to include in the VRLE design. The choice to enable navigation via commonly accessible devices such as phones, iPads, and computers without relying strictly on immersive headsets greatly enhances accessibility, accommodating diverse student circumstances inherent in distance education.

VRLE's have the potential to transform learning experiences previously perceived to be abstract and difficult to understand when taught with traditional approaches. However, immersive experiences can demotivate students as easily as it can inspire learning if not designed effectively and can lead to frustrated students and failure to achieve learning objectives. Careful planning, designing, testing and improvement and implementation of VRLE's is essential to promote understanding.

Lastly, lessons learnt in the implementation process as well as feedback from educators and students have a role to play in improving VRLE designs and should be taken into consideration, for the achievement of optimal learning experiences.

5 Conclusion and Future Work

This paper reported on the development of the VRLE for an online, distance education Software Engineering course by adapting an existing VRMTI framework's – VR

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lesson integration guide for mathematical educational environments. The adapted VR lesson integration guide was used to create digital resources and an immersive VRLE that allows students to learn fundamental Software Engineering concepts in an innovative, meaningful way. The design of VR resources for the Software Engineering course incorporated theoretical frameworks and pedagogical approaches of the VRMTI Framework.

The VRLE implementation was met with excitement and enthusiasm by students expressing an interest to navigate and learn within the immersive learning environment as well as create similar environments in the Software Engineering course. Although no student evaluation was conducted in this implementation and is acknowledged by authors as a limitation of the study, future plans include evaluation of VRLE lesson implementation followed by student feedback that will be gathered. Data collected will be analyzed, and feedback will be used to improve students' learning experience and the course's learning outcomes. Additionally, the future plan includes purchasing licenses for student users, improving Virtual Environments to include more interactivity, increasing the number of tasks and activities at higher levels of the SAMR model and linking with the university's LMS. The research in this study focused on creating Software Engineering VRLE's for students to navigate and enhance conceptual learning, making students consumers of VRLE's. Future task focus will allow students to be creators of VRLE's as a task that encourages consolidation of Software Engineering fundamental concepts.

The Delightex application has been upgraded with more functionalities, including AI features, since its implementation. The new features of the upgrade will be explored and used in future, designed VRLE's to create a more efficient and enhancing learning experience.

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Over-reliance on Artificial Intelligence by programming students at a South African university.

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Abstract. The increasing use of generative artificial intelligence (AI) tools such as ChatGPT, GitHub Copilot, and Claude AI in higher education has raised new questions about their impact on student learning, particularly within software development education. While these tools can enhance productivity, reduce task complexity, and support novice programmers, emerging concerns suggest that over-reliance on AI may lead to cognitive disengagement, poor skill retention, and reduced independent problem-solving. This study, guided by Cognitive Offloading Theory, explores the AI usage among a group of software development students at a South African University. The study employed a qualitative approach through conducting semi-structured interviews with eight postgraduate Information Systems students, and analysed the data using Braun and Clarke's thematic analysis framework. The study found that while AI can support their learning, unchecked reliance by the students may lead to diminished autonomy, reduced skill retention, and inflated confidence not matched by competence. The study suggests an urgent need for structured interventions to balance AI use with the development of critical skills. It justifies further qualitative research into students' cognitive engagement with AI tools, particularly in software development.

Keywords: Artificial Intelligence, Programming, Education, Cognitive Offloading.

1 Introduction

Artificial Intelligence (AI) has evolved from a niche technological advancement to a mainstream tool adopted across industries, including education. This growth reflects not only increased investment but also the widespread integration of AI tools into everyday workflows, learning environments, and personal productivity systems. The introduction of AI tools in education has reshaped how students view and interact with their learning experiences [1]. While these innovations offer clear benefits in terms of efficiency and accessibility, they have also introduced a new set of challenges chief among them, the risk of cognitive over-reliance. Students may become accustomed to outsourcing problem-solving and logic-building tasks to AI tools, leading to diminished engagement with core learning processes and weakening their problem-solving abilities [2]. This behavioural shift is further compounded by growing trust in AI systems,

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where students often accept AI-generated outputs without verifying their correctness [3].

As AI becomes increasingly embedded in academic practice, understanding the implications of this trust and the potential dependency it creates has become a crucial area of inquiry, particularly in education sectors where independent problem-solving is a core learning outcome. In the South African higher education context, the integration of AI presents both unique challenges and opportunities. While AI adoption is accelerating in universities across the country, infrastructural disparities, uneven digital access, and pedagogical readiness raise questions about how students are using these tools and whether they are learning to think critically alongside them. This study arises from those questions, aiming to investigate how AI use in software development education may influence students' independence, confidence, and cognitive engagement. Rather than aiming to quantify the extent of AI use, this study seeks to understand how students make decisions, learn, and feel about the skills and confidence they develop over time.

The study is guided by research questions and objectives aimed at uncovering the behavioural and cognitive patterns of AI reliance among university students. The primary research question seeks to explore the extent of perceived AI over-reliance among students at a South African University. Further questions explore how the over-reliance on AI tools impact these students' independent problem-solving abilities in software development. A student-centred focus informs the inquiry, with alignment between the research goals and theoretical framework ensuring a coherent foundation for the methodological approach.

2 Related Research

The literature has been sourced from a range of academic databases and search engines, including Google Scholar, ScienceDirect, IEEE Xplore, Scopus, and EBSCOhost due to their comprehensive coverage of peer-reviewed journals and research in education and technology fields. To guide and organise the literature, the matrix method [4] has been adopted as a systematic approach for collecting, comparing, and synthesising relevant scholarly sources.

2.1 AI in Software Development Education

The integration of artificial intelligence (AI) tools in software development education has fundamentally altered how programming is taught and learned, with implications for both pedagogical strategy and student learning behaviour [5]. Generative AI technologies such as ChatGPT and GitHub Copilot have been rapidly adopted in higher education settings, offering students assistance in tasks ranging from code generation to algorithm explanation [2, 6]. These tools are credited with increasing academic productivity, reducing time spent on repetitive tasks, and enhancing access to programming support, particularly for novice learners [7]. Despite their practical utility, these tools introduce new pedagogical challenges. AI platforms may accelerate development; however, their outputs can be prone to errors or overly generic when applied to complex

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scenarios, potentially undermining student confidence and encouraging surface-level learning [8]. Similarly, when students rely excessively on AI-generated solutions [7], they may disengage from fundamental programming practices such as debugging, algorithmic reasoning, and critical thinking. While most students have a positive attitude toward AI tools [9], including seeing them as supportive of learning and inclusion, Oyelere and Arulebe [9] also find early signs of behavioural dependence. Students frequently turn to AI tools to complete assignments and generate code, which may have implications for long-term skill development and independent learning practices [9].

2.2 Teaching programming (with AI)

Several researchers argue that the shift to programming with AI necessitates a change in how software development is taught. Becker et al. [2] report that students using AI code generation tools tend to complete programming assignments faster than without these tools, but often fail to engage deeply with the underlying logic and problem-solving strategies involved in coding. They highlight that this may contribute to the illusion of mastery, where students appear to understand programming concepts but struggle when required to apply them independently without AI support. They also expressed concern that students might bypass learning essential foundational skills, such as algorithmic thinking, code debugging, and program design, leading to long-term skill erosion and increased reliance on AI. Becker et al. [2] advocate a refocus on higher-order learning objectives, suggesting that educators place greater emphasis on code evaluation, ethical reasoning, and problem decomposition. Duenas and Ruiz [10] propose that the growing prevalence of AI in education may shift core competencies from technical implementation to skills such as prompt formulation, critique of AI output, and human/AI collaboration. While some studies [5, 11] present optimistic views, suggesting that AI can democratise access to software education, others [1] emphasise the need for carefully scaffolded instructional frameworks. AI tools should complement, and not replace, critical learning processes such as exploring new concepts, analysing information, solving complex problems, and applying knowledge to practical situations [1].

2.3 AI in a South African university context

Although the global academic landscape is rapidly evolving through AI adoption and its promises to enhance administrative efficiency, personalise learning, and support data-driven decision-making, its integration in South African higher education remains limited and uneven [5]. Institutional perspectives in South African higher education underscore the urgency of these concerns, noting that lecturers worry about students' declining proficiency in foundational programming skills due to unstructured and unsupported AI use [11]. Institutional uptake of AI remains cautious, with lecturers expressing both optimism and concern about its impact on blended learning practices [11]. Infrastructure limitations, digital inequality, and the absence of national AI governance frameworks continue to delay widespread implementation [5]. Their findings suggest that South African universities must overcome systemic challenges including inconsistent internet access, a shortage of digital literacy among staff and students, and the

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need for policy development to guide ethical AI integration [5]. These infrastructural and policy gaps, if unaddressed, risk exacerbating existing inequalities and limiting the transformative potential of AI in the education sector [12]. While blended learning models integrated with AI hold some promise to educators, institutional support remains fragmented [11]. While many educators integrate AI into content delivery and assessments, they do so with limited training, unclear guidelines, and minimal institutional backing [11]. Moreover, despite the growing popularity of AI-powered learning tools, there is still uncertainty about their pedagogical value, ethical implications, and long-term effectiveness in the South African HE system. There is a critical need for further research investigating how AI impacts not only teaching practices but also student learning behaviours, dependency, and cognitive development within South African universities [11].

2.4 Ethical Concerns with AI-Assistance

Prior studies identify plagiarism and academic dishonesty as key risks for the integration of AI tools in education. Students using AI to complete assessments may bypass originality and reflective thinking [2, 5, 13]. These tools can obscure authorship, allowing students to present AI-generated content as their own [14, 15]. Bias in AI-generated outputs has been identified as another concern. Models trained on skewed data can reinforce cultural, gendered, and ideological assumptions [16]. Unchecked use of AI in learning environments may reinforce these embedded biases [13, 17]. Data privacy and surveillance risks are also noted as concerns. Students' interactions with AI tools often involve sharing personal information, sometimes without informed consent [10, 13]. Continuous engagement with AI tools may result in unregulated data collection [15]. The dilution of independent thinking and ethical judgment is a recurring theme in the related literature. When students rely on AI without reflective oversight, they risk disengaging from ethical reasoning [1, 2]. Ethical literacy among students is often assumed but not supported by formal training, creating further inconsistencies [11].

2.5 AI-over Reliance

AI over-reliance can be described as students' excessive dependence on AI-generated outputs to complete tasks, often accepting these recommendations without critically evaluating their accuracy or appropriateness [2]. Over-reliance on AI may lead to the erosion of independent thinking, reduced academic engagement, and diminished learning outcomes [15]. Behavioural and psychological impacts associated with AI over-reliance are also evident. Students demonstrate high levels of trust in AI-generated responses, assuming their correctness even when these outputs contain errors [3]. This phenomenon, referred to as "blind trust," weakens active cognitive engagement and discourages students from troubleshooting errors or fully understanding coding logic. The process complements cognitive offloading, in which complex mental tasks are delegated to external technological systems, ultimately weakening students' internal reasoning and reflective learning capacities [10, 15]. Reliance on AI tools can negatively affect students' long-term retention of foundational coding skills, diminishing their

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confidence and proficiency in independent coding [2]. Additionally, this ongoing dependency may limit students' ability to adapt to scenarios where AI support is unavailable or insufficient, thereby reducing their readiness for professional roles that require independent analytical and problem-solving skills [18]. If students fail to develop independent debugging, critical reasoning, and analytical skills due to habitual AI use, their adaptability and problem-solving capacity in industry settings may be severely limited [17]. Understanding the depth and drivers of AI over-reliance is thus essential for ensuring that AI remains a cognitive aid rather than a cognitive replacement [15].

2.6 Long-term impact of AI use

The integration of generative AI tools in programming education has raised concerns about their long-term impacts on students' skill retention and professional preparedness [2, 5, 15]. Long-term skill retention in programming involves students maintaining the ability to independently recall and apply programming principles, logic, and problem-solving strategies well beyond initial instruction [7, 10]. Current research indicates that, while generative AI tools initially enhance students' immediate programming productivity, sustained reliance on these tools often results in reduced retention of foundational programming skills [2, 5, 7]. Specifically, students who regularly depend on AI-generated code demonstrate weaker independent debugging abilities and struggle to apply previously encountered solutions to new problems without AI support [2, 15]. Moreover, the habitual use of generative AI can foster superficial learning patterns, in which students become adept at using AI outputs without truly internalising underlying programming concepts or logic [5, 15].

2.7 Cognitive Offloading

Cognitive offloading is a significant contributor to decreased long-term retention of programming skills, where students frequently delegate complex tasks and cognitive responsibilities to AI [10, 15, 19]. Cognitive offloading through repeated AI interaction has been linked to impaired memory recall and diminished critical thinking abilities, essential components of sustainable programming skill retention [10, 15]. Furthermore, psychological research indicates that persistent cognitive offloading due to AI reliance negatively affects students' motivation and ability to engage actively and independently with programming content over the long term [17].

Although concerns are predominant, some studies highlight the potential for positive outcomes if AI tools are integrated carefully and pedagogically balanced. Evidence suggests that structured educational frameworks that incorporate AI tools alongside traditional, cognitively demanding activities may mitigate skill erosion and even enhance long-term retention of programming skills [1, 3, 16]. Chen & Lin's model [16] emphasises active cognitive engagement and reflective practices as essential pedagogical elements for maintaining long-term programming competencies when using AI tools.

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2.8 Cognitive Offloading Theory

For this study, Cognitive Offloading Theory (COT) [20,23] was chosen for its ability to explain the mechanisms by which individuals transfer cognitive effort to external tools, making it particularly well-suited to examining how and why students delegate problem-solving to AI systems. Unlike the technology adoption model (TAM), which focuses on technology adoption attitudes, or self-determination theory (SDT), which centres on motivation and autonomy, COT illuminates the specific cognitive processes at stake when students use AI as a substitute for independent reasoning. While COT carries limitations in educational contexts, particularly its relative neglect of metacognitive awareness and long-term learning consequences, these gaps make it a productive and appropriate starting point for this exploratory qualitative inquiry.

This study adopts Cognitive Offloading Theory [20] to explore how software development students shift their mental effort from internal problem-solving to external AI tools, and how this behaviour affects their learning outcomes over time. Cognitive Offloading Theory [20], helps explain this phenomenon by suggesting that individuals tend to shift mental effort to external tools, especially when those tools are perceived as accurate or efficient [20]. Cognitive Offloading Theory [20] explains how individuals offload mental tasks such as memory recall, reasoning, or problem-solving to external tools when those tools are perceived to be more efficient or reliable than their own cognitive processes [20]. This theory becomes particularly relevant with the growing integration of generative AI tools such as ChatGPT and GitHub Copilot in Higher Education. Cognitive theory considers three primary constructs: the conditions that trigger offloading (Inputs), the use of generative AI tools (Process), and the behavioural and cognitive effects (Outputs) of using such tools.

The first construct [20] examines the factors that influence students' decision to offload mental effort. These include the task difficulty, time pressures and student readiness. The task difficulty refers to complex or unfamiliar programming tasks that increase cognitive strain, thereby prompting students to seek AI support. Time pressures refer to strict academic deadlines that create urgency, encouraging students to offload tasks to AI for faster completion. Student readiness refers to limited confidence or foundational knowledge that makes some students more inclined to rely on AI. These factors guide the learner's metacognitive evaluation, where they assess whether to proceed independently or defer to AI assistance.

The second construct [20] captures the process of behavioural offloading, during which students actively use generative AI tools to perform tasks that would typically require internal cognitive effort. These tasks may include writing code, debugging, or exploring conceptual understanding. While initial use may be strategic, repeated engagement without critical reflection often leads to automatic dependency, where AI becomes the default mode of problem-solving.

The final construct [20] outlines the outcomes of cognitive offloading, divided into two categories namely behavioural and cognitive impacts. Students begin to consistently bypass their own cognitive processes, allowing the AI tool to become the primary agent of problem-solving. This behavioural dependency often leads to minimal self-verification or reflection on AI outputs. In the longer term, students struggle to retain

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core programming concepts and logical thinking due to reduced mental practice. As AI becomes more trusted, students' belief in their own problem-solving abilities declines. Ultimately students exhibit a diminished ability to independently debug, adapt code, or approach unfamiliar problems without AI support.

3 Methods and Materials

This study used a qualitative research approach to better understand how students rely on generative AI tools in the context of software development education, focusing on both behavioural and cognitive aspects. The study was grounded in the pragmatist research philosophy [21], which aims at understanding practical behaviours and their implications in real-world contexts. Pragmatism views knowledge as instrumental; its value lies in its ability to inform and improve action [21]. Using Cognitive Offloading Theory as the core theoretical framework for this study aligns well with the core ideas of pragmatist philosophy. The theory helps explain how and why people shift mental tasks to technological tools [20], which aligns with pragmatism's focus on exploring practical actions, behaviours, and outcomes in the real world [21].

This study focused on a group of eight postgraduate Information Systems (IS) students at a South African University. Honours-level Information Systems students were chosen due to their deep involvement in programming, hands-on project work, and real-world system development, all of which require tackling complex problems and using AI-powered coding tools. A purposive sampling approach was used, with participants selected based on their self-reported experience with AI tools such as ChatGPT, Claude AI, Cursor, or Deepseek in academic software development tasks. This was confirmed during the recruitment stage through a short self-assessment in a Google Form to better understand which students use the common AI tools.

Data were collected through semi-structured interviews lasting 20-30 minutes. These interviews were designed to explore students' experiences with AI tools in programming contexts. The interview questions were derived from the literature review, theoretical framework, and research objectives (Appendix E: Research Instrument). Interviews were conducted via Microsoft Teams or in person, depending on participant availability, and all interviews were recorded and transcribed with the students' consent.

This study adhered to ethical standards set by the University concerned. Prior to the commencement of data collection, ethical approval was obtained from the University's ethics in research committee, and permission to conduct research with students was obtained from the University's department of student affairs. Following ethical approval, participants signed consent forms agreeing to the sharing of their interview data. Transcripts were anonymised prior to analysis.

3.1 Data Analysis

The thematic structure for the data analysis was derived using the Braun and Clarke's [22] framework, with NVivo software supporting the code generation, categorisation,

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and visualisation. Data visualisation features in NVivo, such as Word Trees, were used to understand common words across themes within codes better. The iterative process enabled the researchers to revisit and refine codes as insights emerged during analysis continually.

4 Findings

Ten themes were derived from the thematic analysis and are listed in Table 1 below, along with further discussion.

Table 1. High-level Themes

#	Factor	Files	# References
1	Use of AI Tools	6	12
2	Time Pressure	6	8
3	Student Confidence	7	11
4	Critical Thinking	6	12
5	Task Difficulty	2	2
6	Convenience	3	6
7	Effort vs convenience	7	11
8	Technical Readiness	5	9
9	Over-reliance	6	12
10	Long term skill retention	7	23

4.1 Usage of AI Tools

Students described using AI tools for a range of tasks, including debugging, code scaffolding, API clarification, documentation generation, and even architectural design. ChatGPT and Copilot were often "open in the background," ready to intervene at a moment's notice. S6 compared it to a personal tutor always on standby: fast, reliable, and free of judgment. "*I use AI to scaffold code (like setting up REST endpoints), to generate first drafts of documentation, and to plan system architecture options. Over time I moved from curiosity to workflow integration." (S6)*

I use ChatGPT a lot. I have the paid version as well, ChatGPT 5, so it's quite, it's quite like, involved. I use it more of a general in my life right now, so you could think of it as the Google for me, like people always go to Google, but I've been for a ChatGPT right now because it just gives more. I just give more because it's like customised to my liking. It just gives more straight to the point answers and it explains the answers in a way that I understand it. (S8)

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Students relied on a variety of tools for generating explanations, code examples, and initial fixes, valuing its accessibility and tailored responses.

- ChatGPT for explanations, examples, code generation, and first-pass fixes. *(S1, S2, S3, S6, S8)*
- GitHub Copilot *"is always open next to me"* to suggest completions and snippets. (S5)
- Claude/Deep Seek was used occasionally alongside ChatGPT for cross-checking. *(S1, S5, S9)*

This kind of embedded use aligns with Risko & Gilbert [20] who observe that repeated offloading can shift from being strategic to habitual from a one-off shortcut to an ingrained workflow.

4.2 Time Pressures

Time pressure refers to assignment/task deadlines, concurrent work-study demands, or fatigue-driven urgency that compresses deliberation time. In the context of Cognitive Offloading Theory, students opted for external aids when the expected efficiency of offloading (accuracy × speed) outweighed the effort of internal processing, particularly under effort-minimisation constraints. These aspects were evident in student comments such as "*We had a hard deadline… I used AI to generate and explain patterns, then wrote unit tests."* (S4), "*It's **definitely time pressure** that leads me to **copy-paste**… I'm **not going to rewrite** it." (S5), "When there's no time… I just use it; saves time." (S1), "Deadline and I was also working… I asked GPT to produce this program; I'd fix later". (S6), "I default to AI for simple, repetitive tasks; in deadline weeks I use it to review." (S7) and "Docs weren't clear, so I prompted AI to ingest them and tell me exactly what I need." (S7).* These students described offloading to AI as a rational response to overlapping assignments, work/study commitments, or exhaustion, thereby prioritising efficiency over deliberate engagement. For some students, AI became the default tool during high-pressure periods, not due to a lack of capability but as a strategic choice to manage time constraints. This aligns with the findings of Laato et al. [7], who note that students use large language models such as ChatGPT to accelerate task completion under time constraints.

4.3 Student Confidence

Students with limited programming confidence or weaker foundational knowledge seem to rely more frequently on AI tools to initiate tasks or validate their approaches. Many of the students described AI as a confidence booster, acting as a "safety net" to help them start or confirm their work. For example, S4 explained that "*Sometimes I know what I'm trying to do, but I don't know how to start; that's when I ask ChatGPT"* and S3 emphasised that *"It boosts confidence because I know I can cross-check my approach quickly. But I'm deliberate about not outsourcing judgment" (S3).*

This emphasises AI's role in providing rapid feedback without replacing critical evaluation. As student (S6) remarked, *"It definitely gives you a confidence boost because… you can understand certain frameworks, especially in software development",*

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highlighting how AI facilitated engagement with complex tasks. However, some students expressed mixed feelings, noting that AI's availability could undermine their self-assurance. S4 stated that, "*When I work without AI, I feel like I'm not doing the right thing, to be honest. Even though I can feel… this is how it's supposed to go",* indicating a reliance on AI for reassurance even when they understood the task.

4.4 Critical Thinking

These students reported that their AI use reduced their independent problem-solving and deeper engagement with coding tasks. For instance, student (S1) shared that *"I don't try to fix it on my own anymore. I go to AI"*, suggesting a shift away from self-directed problem-solving. Student (S2) indicated that *"I kind of rely on AI so much that it's definitely hindered my ability to actually code a program just by myself*", pointing to a perceived decline in coding skills due to frequent AI use. This sentiment was echoed by student (S7) who noted that *"Because I use it so much… I'm not really understanding the concept in depth, and that's kind of bad because when it comes to exams, then I really have to grind"*, indicating that over-reliance on AI led to shallow learning and delayed mastery of concepts. Some of the students valued working without AI for deeper understanding, with student (S3) stating, *"Without AI, I feel slower but more immersed. I rely more on fundamentals, documentation, and experimentation. It's good for depth and memory"*. These findings align with those of Becker et al. [2], who observed that students with lower confidence levels tended to use AI as a scaffold, which may reduce self-directed effort and critical engagement with coding tasks. The reliance on AI as a confidence booster or problem-solving aid highlights its role as an external cognitive resource, particularly for students navigating uncertainty or limited foundational skills.

4.5 Task Difficulty

A further factor influencing students' use of AI for programming was task difficulty, characterised by the complexity or unfamiliarity of programming problems, which prompted students to seek assistance from AI tools. Students often made rapid judgments about whether a task warranted independent effort, frequently opting for AI when faced with challenging concepts such as recursive algorithms or syntax-heavy logic. For example, one student explained, *"If I know it's a difficult algorithm or recursion, I don't even bother. I just paste it in ChatGPT" (S1)*, indicating an immediate reliance on AI for complex tasks. Students also describe strategic approaches to using AI for difficult tasks, balancing independent effort with external support. One student noted, "*It depends on the complexity of the problem… I try to understand before going to [ChatGPT] because I've realised that if you don't understand the problem first… you might take errors as they are" (S4),* emphasising the importance of initial comprehension to avoid blind acceptance of AI outputs. Similarly, another student remarked, "*If AI is available, I might paste a minimal snippet and ask for likely failure points or complexity hotspots. But I still validate by stepping through locally" (S3),* illustrating a

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deliberate process of using AI to address specific challenges while maintaining critical engagement.

4.6 Convenience

An emergent factor was the convenience of using AI. While the original theory of cognitive offloading highlights task complexity and cognitive load as core drivers of offloading, our data show that students defaulted to AI tools even for simple tasks, primarily to reduce effort and streamline routine processes. This suggests a shift in behaviour where students no longer reserve AI for complex or time-pressured scenarios but rather incorporate it into day-to-day activities as a matter of convenience. Several students describe habitually offloading tasks such as database queries, syntax corrections, or code formatting; not due to a lack of understanding but because it was easier and quicker than engaging with the task manually. As students (S5&6) noted:

"I default to AI a lot when the tasks are simple and repetitive." (S5)

"Before, I could do really well querying data in SQL… but now I don't even touch anything that has to do with SQL. I just let AI generate any database queries I make." (S6)

The appeal of AI tools as a substitute for personal effort, even in low-stakes scenarios, illustrates a drift towards automatic offloading. This concept is not fully discussed in the cognitive offloading literature. This finding aligns with Duenas & Ruiz as well as Li et al. [10, 23], who caution that habitual convenience-driven AI use may dilute long-term learning and independent reasoning.

4.7 Effort vs. Convenience

The subtheme of *Effort vs. Convenience* highlighted the trade-off students navigated when deciding to offload tasks to AI, often based on task complexity, urgency, or personal capacity. For repetitive or peripheral tasks, such as writing boilerplate code or generating documentation, students readily turned to AI to minimise mental effort. One student explained:

If the task is core to my learning objectives (algorithms, security, data modelling), I do it myself first. If it's scaffolding or repetitive glue code, I use AI. (S3)

This illustrated a deliberate distinction between tasks requiring deep engagement and those suited for automation. Exhaustion also influenced these decisions, one student noted. Another student reflected on emotional and physical exhaustion as a driver for offloading, If *I'm tired and I only have five minutes to think, I'll just use AI and review the code it gives me. (S5)*

Other students described a strategic first-step approach: they try first to do it by themselves before turning to AI only when they get stuck. This reflects an awareness of AI limitations and an effort to retain control over the task:

*I try to understand it by myself… if I can't, then I ask JGPT [ChatGPT] to explain it more clearly. (*S6*)*

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This tension between effortful learning and immediate convenience reveals how cognitive offloading is not always impulsive; it is often calculated, with students trying to preserve cognitive agency in tasks they perceive as important to their growth.

4.8 Technical Readiness

Students reported mixed results, with AI use boosting confidence and productivity in the short term but raising concerns about diminished independent coding skills and long-term professional readiness. Students' technical readiness highlighted how AI influenced students' confidence in tackling coding tasks and their perceived preparedness for professional environments. One student noted, *"If someone told me to code something in JavaScript and I don't know a single piece of JavaScript, I would be confident to take that task… because I know I could ask AI for help and get an output"* (S2), illustrating how AI's availability enhanced their willingness to engage with unfamiliar tasks. However, this confidence was tempered by concerns about actual skill development. Another student (S3) reflected, *"If you just rely on AI without actually thinking about things deeply, you can easily fall into a trap whereby you think you have a certain capability, like you can produce apps on your own, whereas when you get to the workplace, you realise, no, this was not me" (S3*), suggesting that AI-driven outputs could create a false sense of competence. Some students anticipate a shift in their future roles, with one stating, *"I expect to spend more time on architecture, systems thinking, and product tradeoffs, with AI assisting more on implementation details. My value will be in decision-making and ensuring quality" (S3*), indicating a strategic adaptation to AI's role in professional settings.

4.9 Over-Reliance

The factor of *over-reliance* captured students' concerns about their dependence on AI tools. For instance, one student admitted*, "I kind of rely on AI so much that it's definitely hindered my ability to actually code a program just by myself"* (S2), pointing to a perceived decline in independent coding skills. Similarly, another noted, "*I didn't rely on it, but now almost every now and then when I develop software or applications, I go to [ChatGPT]" (S4),* indicating a growing tendency to turn to AI as a default resource. In contrast, working without AI was described as fostering deeper engagement, with one student explaining, *"Without AI, I feel slower but more immersed. I rely more on fundamentals, documentation, and experimentation"* (S3), highlighting the trade-off between efficiency and depth.

4.10 Skill Retention

Long-term skill retention reflected students' apprehensions about the sustainability of their skills in an AI-driven future. One student (S4) expressed a concern, stating*, "I feel like I'm not going to be able to [program] by myself without AI in five years because there's a lot of things to learn in [programming] and there's a lot of new terminology"* (S4), reflecting fears of becoming overly dependent on AI. Another student warned, *"If*

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we depend only on AI… our critical skills might [suffer]" (S8), emphasising the importance of balancing AI use with independent learning to maintain long-term competence. These findings suggest that while AI enhances short-term productivity, it may pose challenges for developing robust, independent technical skills required for industry readiness.

5 Discussion

This section presents the interview findings, organised according to the three dimensions of Cognitive Offloading Theory: Inputs, Process, and Outcomes. There appears to be a widespread and growing reliance on AI tools, especially ChatGPT and GitHub Copilot, among the students in this study. AI tools have shifted from being supplementary aids to default problem-solving resources, especially during time-constrained or high-pressure scenarios. Students described AI as always open in the background, ready to assist with debugging, scaffolding, or even design tasks. For many, the decision to use AI was not driven by lack of knowledge but by habit and convenience, an indicator of behavioural automation. This aligns with Becker et al. [2], who note that when AI tools are repeatedly used without strategic intent, reliance becomes habitual. Students' perception that AI enhances productivity and accelerates performance mirrors the findings of Oyelere and Aruleba [9], who also find early signs of behavioural dependence among Sub-Saharan university students.

However, unlike previous work, this study identifies not just the presence of over-reliance but its depth, evolution, and emotional normalisation over time. AI over-reliance seems to reduce these students' willingness to engage in effortful problem-solving. Students acknowledged skipping critical thinking steps, avoiding complex logic, and even bypassing debugging in favour of copy-pasting AI-generated solutions. This was especially true under time pressure, fatigue, or cognitive overload. One student confided *"I don't try to fix it on my own anymore. I go to AI"* (S5) capturing the core issue: internal reasoning is frequently outsourced to AI tools. This finding is directly supported by Cognitive Offloading Theory, which posits that individuals delegate cognitively demanding tasks to external systems when the perceived benefits outweigh the cognitive cost [20]. It is also consistent with Zhai et al. [15], who found that over-reliance on AI leads to reduced engagement in debugging and troubleshooting core practices in problem-solving education.

The findings therefore suggest that cognitive offloading to AI does not merely supplement problem-solving capacity it reshapes it by shifting cognitive ownership away from the student. The relationship between trust in AI and coding confidence emerged as paradoxical. On the one hand, students described AI as a "confidence booster" or "safety net", allowing them to begin or validate tasks with less anxiety. On the other hand, their dependence on AI gradually eroded their belief in their own unaided capabilities. Several students expressed a concern that without AI, they would feel lost or unsure of their solutions, even when they understood the problem.

This duality reflects the phenomenon of "blind trust" described by Yilmaz et al. [3], where students assume AI output is correct without sufficient verification. Over time,

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this perceived reliability creates a false sense of competence, leading students to feel confident completing tasks but unable to replicate that performance in unsupported environments, such as exams. Becker et al. [2] similarly caution that unchecked trust in AI reduces self-reflective practices, which are critical for developing authentic programming proficiency. Taken together, the findings directly address the study's two research questions. The primary research question exploring the extent of perceived AI over-reliance among students at a South African university is answered through the themes of Usage of AI Tools, Over-Reliance, and Convenience, which collectively demonstrate that AI use had shifted from strategic to habitual for most participants, with students describing AI as embedded in their daily workflows and increasingly difficult to disengage from. The second research question examining how over-reliance on AI impacts students' independent problem-solving abilities, is addressed through the themes of Critical Thinking, Effort vs. Convenience, Skill Retention, and Student Confidence, which reveal that habitual AI use progressively eroded students' willingness and ability to engage in independent debugging, reasoning, and deep conceptual engagement.

6 Conclusion

This study set out to explore the implications of generative AI use among postgraduate students in software development. Drawing from Cognitive Offloading Theory, the research revealed a complex interplay between convenience, trust, and cognitive disengagement. This study uncovered nuanced interactions between the three phases of cognitive offloading.

Inputs such as time pressure, task difficulty, and low confidence may lead to reliance on AI tools (Process), which, over time, produces outcomes such as diminished critical thinking and perceived skill erosion. Importantly, this study found that these phases are not linear, but cyclical. For example, a student under time pressure might offload their cognitive processes to AI, which may lead to a shallow understanding and reduced skill confidence, thereby further increasing reliance on AI in the subsequent task. This cyclical relationship was also observed in the trade-offs that students made between effort and convenience. As shown in the process theme, students deliberately chose to engage deeply with some tasks while offloading others, typically those seen as repetitive. However, this boundary blurred over time, and some students began defaulting to AI even for core logic.

As AI becomes more embedded in daily academic work, institutions might risk producing graduates who lack deep technical reasoning due to unchecked reliance on automation. This is especially true in the context of South Africa, where there is a greater digital gap and where the risk of over reliance on AI is greater. As such, there is an urgent need to integrate AI-aware pedagogy, foster students' metacognitive awareness, and design interventions that preserve deep learning while embracing technological progress.

This study contributes to the emerging discourse on AI in education by showing that the true challenge lies not in the tool itself, but in the behaviour it cultivates. If left

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unmoderated, AI use in education may create graduates who are efficient but cognitively underprepared for real-world programming tasks.

Future research should extend this inquiry to larger, more diverse student populations across multiple South African institutions and examine whether structured AI-use frameworks, such as requiring students to attempt problems independently before AI consultation, can meaningfully reduce cognitive offloading while preserving AI's productivity benefits. The South African context, with its distinctive digital inequalities and infrastructural constraints, represents a particularly important site for this next phase of investigation.

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Industry Perspectives on Industry Advisory Board Effectiveness in Higher Education

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Abstract. Industry Advisory Boards (IABs) are established mechanisms used by Higher Education Institutions (HEIs) to support university-industry collaboration. Research on the effectiveness of IABs from industry stakeholders' perspectives is limited. This study addresses this gap by exploring industry members' perceptions of IAB effectiveness. The study specifically focuses on understanding how industry stakeholders perceive their roles, contributions, and the impact of IABs on curriculum relevance and graduate employability. A mixed-methods approach was followed, using an online survey consisting of quantitative and qualitative components. Participants were IAB members from South African universities. The findings indicate that industry members require improved communication and feedback, a policy on their roles and responsibilities, and more frequent online meetings. The challenges they face include time and availability constraints. The findings indicated that graduates were academically prepared but not industry-ready, and that there should be closer industry-departmental collaboration and interaction. These findings highlight a gap between the intended and actual functioning of IABs, particularly in terms of responsiveness and engagement. The study contributes to a more balanced understanding of IAB effectiveness and offers insights to strengthen university-industry collaboration in computing education at HEIs. The study further provides practical recommendations for enhancing the structure, governance, and ongoing engagement of IABs.

Keywords: Industry Advisory Boards, University-Industry Collaboration, Graduate Employability.

1 Introduction

Relevance is of high importance in the field of computing education (Computer Science, Information Systems and Information Technology (IT)), with Higher Education Institutions (HEIs) having to prepare graduates for a fast-changing IT industry and environment. Keeping curricula updated to meet rapidly changing demands is difficult

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and may result in a significant skills gap [1]. It has become increasingly clear that it is essential to bridge this gap between academia and industry [2].

The use of Industry Advisory Boards (IABs) is well established as one of the key mechanisms for aligning academia and industry. An IAB has members from academia and industry and provides guidance on the latest industry developments, technologies and trends. Literature clearly demonstrates the importance of IABs for, amongst others, technology education [3]. Academic institutions must engage with industry to ensure that teaching and learning, as well as research, remain relevant [4]. IABs increase employer input into curriculum and student development, informing continuous improvement [5] and contributing to graduate employability and workforce readiness [6]. However, the extent to which these intended benefits are realised in practice remains unclear.

Industry engagement can bring relevance to the curriculum but requires valuable time from both industry and academia [7]. The challenges and opportunities of working with IABs are multi-layered [3], and academic and industry partnerships must be designed to benefit all stakeholders to ensure sustained engagement. Zahra et al. [8] referred to limited research on the role and structure of IABs. A study by Taylor et al. [9] identified independent factors that had a positive influence on the effectiveness of an IAB, namely IAB membership, IAB meetings and documentation, and IAB stakeholder (member) knowledge and responsibilities. This study, however, was from the viewpoint of heads of departments (HODs). Even though industry engagement is a vital aspect of higher education [10], there is limited research available on the effectiveness of IABs from the viewpoint of industry stakeholders. Lyman [3] also mentions the need for further research to gather feedback from IAB stakeholders on the effectiveness of existing IABs.

To summarise, even though IABs are established mechanisms in HEIs, there is limited literature on their effectiveness, particularly from an industry perspective. This creates an imbalance in the literature, where industry participation is discussed but the perceptions of IAB stakeholders are underexplored. This may result in misalignment between expectations and outcomes and reduced collaboration over time.

Thus, the gap this paper will address is the lack of research on industry perspectives on the effectiveness of IABs. This research aims to capture and analyse industry stakeholders' perceptions of IAB effectiveness and their role in curriculum transformation, and to compare these perceptions with those of academic stakeholders (from a previous study). The contribution of this research is a more balanced understanding of university-industry dynamics in computing education.

The research problem and objectives are presented in Section 2, followed by the literature review (Section 3), research methodology (Section 4), findings and discussion (Section 5), and conclusions and future research (Section 6).

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2 The Research Problem and Research Objectives

The need for further research to gather feedback from IAB industry stakeholders on the effectiveness of existing IABs in computing departments is emphasised by Lyman [3]. Söderlund et al. [11] refer to limited studies that have been conducted on the best practices and identifying the factors that contribute to the effectiveness of IABs. Zahra et al. [8] indicated that further research needs to be conducted on IABs to assist computing departments in better understanding the role and responsibilities of IAB members. Collectively, these studies point to a lack of comprehensive understanding of how IABs operate effectively in practice.

The research problem investigated in this study is that the perceptions of industry stakeholders on the effectiveness of their roles and responsibilities as IAB stakeholders have not been investigated. This gap limits the ability of academic institutions to fully leverage industry input for curriculum and programme improvement. Without incorporating industry perspectives, efforts to align curricula with real-world demands may remain incomplete or ineffective. The objective of this study was to determine industry stakeholders' perceptions of the IAB on which they serve and to investigate the benefits, challenges, and the key skills graduates are lacking from an industry perspective.

The study aims to provide insights that can enhance collaboration between academia and industry and improve graduate readiness. The research questions addressed in this study are:

- RQ_1: How do industry stakeholders perceive the benefits and effectiveness of IABs in enhancing curriculum relevance and graduate employability?
- RQ_2: What factors influence the effectiveness of IABs, particularly in terms of structure, communication, and implementation of recommendations?
- RQ_3: What are the key challenges and barriers that hinder effective collaboration between universities and industry through IABs?
- RQ_4: What skills do industry stakeholders perceive as lacking in recent graduates, and how should academic programmes evolve to address these gaps?
- RQ_5: What strategies can strengthen IABs and improve university-industry collaboration in rapidly changing technological environments?

Together, these research questions are designed to provide a comprehensive understanding of IAB effectiveness from an industry perspective while enabling comparison with academic viewpoints. This also ensures that the study captures both evaluative and forward-looking insights, linking current challenges with potential improvements.

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3 Literature review

The literature review in this section addresses relevant terminology, the structure of IABs, dynamics between academia and industry, and Stakeholder Theory.

3.1 Terminology and structure of IABs

There are many definitions of IABs, but all of these agree that the key role of an IAB is to serve the university and provide it with feedback on what is important for organisations outside HEIs that will hire their graduates [12]. IABs in HEIs are composed primarily of industry stakeholders who provide advice on education programmes and their relevance. The key role of an IAB is to introduce an industry perspective into academic activities.

Existing literature portrays the need for academics and industry stakeholders to collaborate, resulting in significant benefits for both parties. HEIs are increasingly expected to build closer relationships with industries [13]. IABs typically consist of alumni and industry stakeholders of varying roles or levels. Lyman [3] writes that junior to senior-level members were excellent in curricular feedback and skills discussion for industry preparation, but lacked support for financial resources. This highlights the importance of appropriate and diverse IAB membership.

A study conducted at HEIs in computing fields in South Africa [14] showed that the average size of an IAB was 20 members, including departmental members, alumni and other industry members and one undergraduate and one postgraduate student representative. Meetings were held 1–2 times a year, and the duration of the average meeting was 3 hours. Topics discussed include the curriculum, activities, strategies, industry trends and graduate employability. These characteristics illustrate how IABs are typically operationalised in practice.

In this study, IAB effectiveness is seen as the extent to which IABs meaningfully influence curriculum relevance, graduate employability, and strategic alignment between academia and industry, while creating mutual value for both stakeholder groups. This definition guides the evaluation of IAB effectiveness in this research.

3.2 Dynamics between academia and industry

In fields such as science and engineering, building strong connections between HEIs and industry can benefit both sides, helping industries grow while HEIs improve their research and teaching [2]. Sustainable collaboration requires active effort on both sides and helps both HEIs and industry members to achieve goals that are difficult to accomplish in isolation [13]. However, differences in priorities may create challenges for sustained collaboration.

Hazrat et al. [15] state that “It is evident that future industries will require their employees to be skilled in multiple fields.” This highlights the increasing demand for interdisciplinary and adaptable skill sets among graduates. This reinforces the need for continuous curriculum renewal informed by industry input.

Literature highlights that IABs enhance curriculum quality, employability, research impact, and industry engagement [4; 10; 13]. Collectively, these studies demonstrate

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the value of IABs for both academic institutions and industry stakeholders. The benefits identified for industry include the opportunity to recruit graduates, build relationships with faculty, network with students and enhance organisational visibility [16]. These benefits, however, require ongoing time and engagement from industry partners.

3.3 Academic theory

Stakeholder Theory is relevant to this study. A stakeholder is defined as any entity that can influence or is influenced by organisations [17]. It states that organisational effectiveness depends on the alignment of key stakeholders [18]. Within HEIs, industry partners constitute a critical stakeholder group. Later developments of Stakeholder Theory [19; 20] further emphasise the importance of creating value for stakeholders and managing relationships effectively.

Stakeholder Theory provides a basis for examining how industry representatives perceive their roles, responsibilities, and impact within IABs. From this perspective, IABs function as platforms for stakeholder engagement, designed to align the expectations of academia and industry. However, such alignment requires active management and cannot be assumed. The absence of investigation into industry members' perceptions limits understanding of whether IABs facilitate alignment. This study addresses this gap by examining IAB effectiveness from the industry perspective.

4 Research Methodology

The study followed a mixed-methods approach. The industry stakeholder perspectives of IABs questionnaire were compiled from similar studies discussed in the literature [9]. The IAB industry stakeholders' perceptions questionnaire consisted of biographical details (position, job title, etc.), open-ended questions and Likert scale statements. This combination of closed- and open-ended questions enabled both structured data collection and richer qualitative insights.

The IAB questionnaire was captured using the online survey tool, QuestionPro. The participants were IAB members from three HEIs at South African universities. An email was sent by the departmental liaison to the industry stakeholders (members) requesting them to participate in the survey, and fifteen responses were received over a two-week period. While the study includes fifteen respondents, the sample consists of senior industry stakeholders with direct experience of IAB participation, which enhances the credibility and relevance of the findings for exploratory analysis.

The quantitative data from the survey were analysed using descriptive statistics. The qualitative questions were thematically analysed using the large language models (LLM) Claude [21] and ChatGPT, enabling the efficient identification of recurring patterns and themes. The responses to each question were copied, and the two LLMs were prompted to thematically analyse the responses into five themes, including data evidence. To ensure validity and reliability, the generated themes were critically reviewed, refined, and interpreted by the researchers, thereby maintaining analytical rigour and minimising potential bias introduced by automated processing. Infographics were generated after the thematic analysis.

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The objective of this study was to determine industry stakeholders' perceptions of the IAB on which they serve and to investigate the benefits, challenges, and the key skills graduates are lacking from an industry perspective. From this, five research questions were formulated. These research questions guided both the design of the survey instrument and the subsequent analysis of the data.

The information in Table 1 shows how each question in the questionnaire can be linked to the 5 research questions. The mapping presented in Table 1 demonstrates the systematic alignment between the research questions and the survey instrument, thereby strengthening the methodological rigour of the study.

Table 1: Survey questions linked to research questions

Research Question and Focus Area	Survey item
RQ_1. Perceived benefits and effectiveness of IABs.	• Importance of IABs for improving computing education. • Main benefits of having an IAB. • The IAB meeting frequency.
RQ_2. Governance, communication, and operational effectiveness.	• Impactful contributions. • Role and responsibilities as an IAB member. • Maintaining academic standards and programme quality. • Timely and effective communication. • HEIs acting on IAB recommendations. • IAB members are well informed about the department's programmes, curriculum and strategic direction. • Availability of IAB policies and outcomes. • Time constraints.
RQ_3. Challenges and systemic barriers.	• Main challenges for an IAB. • Biggest barriers to effective collaboration.
RQ_4. Graduate skills gap and curriculum alignment.	• Satisfaction with the skill levels of recent computing graduates. • Key skills lacking in recent graduates.
RQ_5. Strategic improvement and future direction.	• Advice to improve the functioning of the IAB. • Beneficial collaboration types. • Additional comments, insights and concerns.

Ethics

The North-West University Ethics Committee approved the study. Ethical considerations included voluntary participation, informed consent, and the protection of participant anonymity throughout the research process.

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5 Research Findings and Discussion

The findings are interpreted in relation to the research questions and existing literature to provide a comprehensive understanding. While each survey item is mapped to a specific research question, some findings (e.g., communication, engagement, and skills gaps) are interrelated and therefore discussed across multiple sections from different analytical perspectives.

5.1 Background of respondents

The IAB industry stakeholders survey was completed by 15 IAB industry stakeholders from three HEI's in South Africa. Five respondents were at the Director / Executive level, and six were Project managers /Team leads. The job titles included Chief Information Officer (CIO), Chief Technology Officer (CTO) and Chief Operations Officer (COO). Six respondents worked in the IT industry, four in finance, three in manufacturing and two in consulting. This indicates that the respondents represent experienced professionals from diverse sectors. Four members served '1–2 years' and 10 '3–5 years' on the IAB. One respondent served for more than 5 years. This suggests that most respondents have sufficient experience with IABs.

5.2 Perceived value and impact of IABs

RQ_1 examines the role and effectiveness of IABs in enhancing curriculum relevance and graduate employability. All the respondents indicated that they believed that IABs improve computing education. The majority (n=14) indicated that the IAB meeting frequency is adequate for meaningful engagement. This contrasts with qualitative feedback suggesting a need for more frequent engagement.

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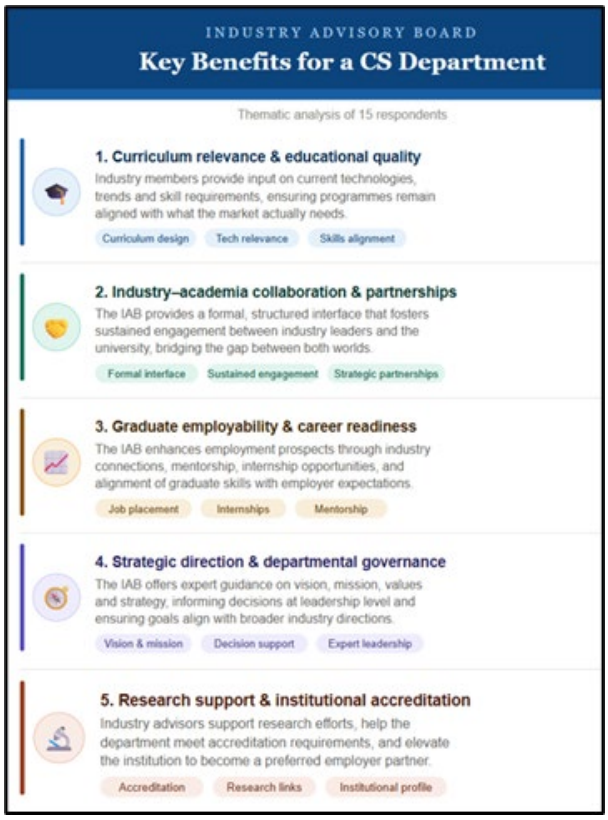


Fig. 1. Key benefits for a computing department (Claude generated).

The thematic analysis for the question on the main benefits of having an IAB is presented in Figure 1. The most frequently cited benefit was that IAB members keep academics informed about evolving technologies, trends and required skills, ensuring programmes reflect industry needs. Respondent 2 said, "Getting input on academic matters from industry members. Keeping academics informed of what is happening in industry". Respondents also highlighted improved job placement outcomes, internship pipelines and mentorship as key benefits. Additional benefits include support for accreditation, applied research and institutional reputation. These findings align with existing literature that positions IABs as contributors to both academic quality and employability outcomes [4; 10; 13]. IABs play a critical role in aligning curricula with industry needs by providing up-to-date insights on technologies, skills, and employability pathways.

5.3 Governance, communication and operational effectiveness

RQ_2 examines factors influencing the effectiveness of IABs, particularly in terms of structure, communication, and implementation of recommendations. The frequency distributions for the items relating to IABs (n=15) success factors are presented in Table 2. The responses to the 5-point Likert-scale options Strongly Disagree/Disagree and Agree/Strongly Agree have been combined for reporting purposes. The item in Table 2,

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with the lowest mean score (μ=3.1), was that the university did not act on advisory board recommendations in a timely and visible manner.

Table 2: Frequency distributions of items relating to *IABs* (n=15)

Items	Disagree (n)	Neutral (n)	Agree (n)	μ
I clearly understand my role and responsibilities as an IAB member.	3	2	10	3.5
My contributions have an impact on improving relevance and employability.	0	1	14	4.4
Communication between the university and stakeholders is timely and effective.	0	2	13	4.2
Time constraints make it difficult for me to participate meaningfully.	1	4	10	3.7
The university acts on advisory board recommendations in a timely and visible manner.	4	5	6	3.1
IAB members should have a relevant qualification and industry expertise.	0	3	13	4.2
IAB members should be well informed about the department's programmes, curriculum and strategic direction.	0	0	15	4.4
IAB policies, membership composition and meeting outcomes should be publicly available on the department's website.	1	5	9	3.8
IABs contribute to maintaining academic standards and programme quality.	0	3	12	4.3

Most respondents (n=14) agreed that their contributions had an impact on improving curriculum relevance and graduate employability, and all agreed that IAB members should be well informed about the department's programmes, curriculum and strategic direction. Three members indicated that they did not clearly understand their role and responsibilities as an IAB member. This indicates that role clarity remains an area for improvement.

Only 6 respondents agreed that the university acts on IAB recommendations in a timely and visible manner. This highlights a gap between industry input and institutional responsiveness. These results can be compared to the results of an earlier study by Taylor et al. [9], where the perceptions of academic members were reported:

1. Some industry stakeholders reported unclear roles and responsibilities, while the feedback from academia members (earlier study) emphasised that members must understand roles and be familiar with programmes and strategy. Both perspectives highlight the importance of role clarity, but while academia assumes clarity exists, industry feedback shows this is not consistently achieved in practice.
2. Both groups clearly recognise IABs as valuable mechanisms for curriculum relevance and employability outcomes.
3. Both perspectives strongly agree that informed and knowledgeable members are critical for IAB effectiveness.

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4. There is clear agreement that time and availability are major barriers, affecting consistent participation and engagement.
5. Both perspectives acknowledge limitations of current meeting structures, with industry expressing a stronger need for increased engagement frequency.
6. Both perspectives highlight institutional inertia, confirming that slow implementation is a shared and systemic issue.

The comparison reveals a key difference, as industry experiences more practical challenges (role clarity, responsiveness), while academia focuses more on structural and theoretical effectiveness.

5.4 Challenges and systemic barriers

RQ_3 examines the key challenges and barriers that hinder effective collaboration between HEIs and industry through IABs. The thematic analysis for the question on challenges is presented in Figure 2. The most frequently mentioned challenge was that industry professionals struggle to give sustained attention and participation. Participant 8 said, "Time and commitment from all advisory board members" was a major challenge.

Multiple respondents indicated that universities are unable to implement suggestions in a timely manner and that the impact of meetings is often unclear. Participant 2 indicated that "Providing input and suggestions that the department cannot implement in a timely manner" remained a challenge and could reduce stakeholder motivation over time. Sustained engagement is the primary challenge, with time constraints and limited availability reducing meaningful industry participation.

The theme "Keeping pace with rapid technological change" highlighted the impact of the AI revolution on both required skills and advisory capacity. The theme "Producing work-ready graduates" underpinned many responses, with concerns about recruiting suitable members and addressing the employability gap.

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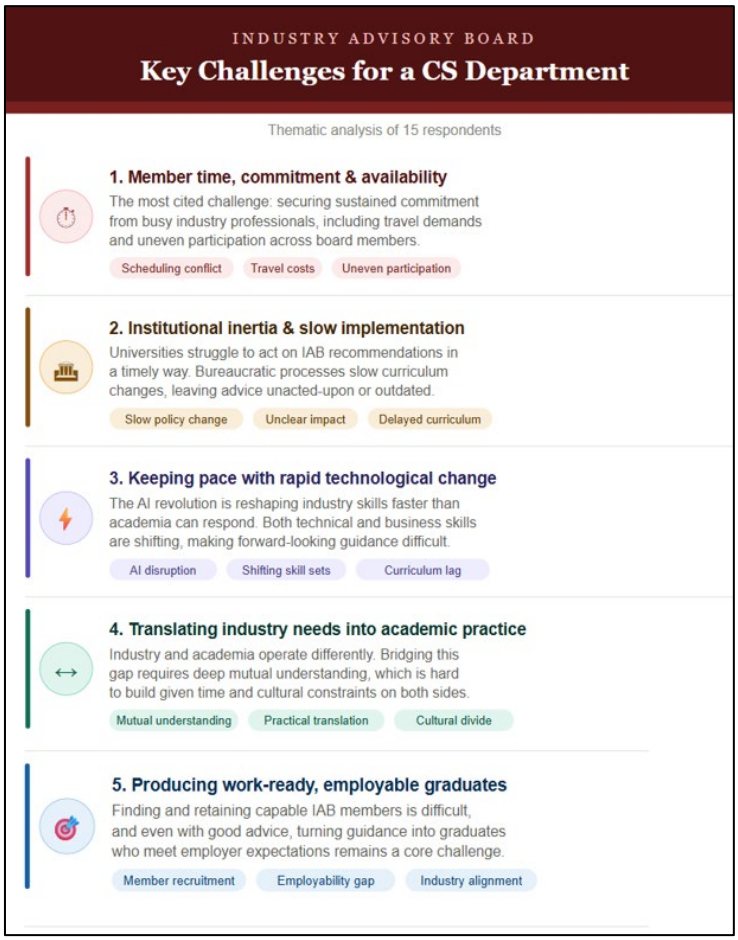


Fig. 2. Key challenges for a computing department (Claude generated).

The thematic analysis for the question "What do you think is the biggest barrier to effective university-industry collaboration?" is presented in Figure 3. Structural misalignment between universities and industry, particularly slow institutional processes and differing priorities, limits effective collaboration. The first theme indicates that industry wants agile, tech-current graduates, while universities are structured around longer-term academic goals and individual research interests. HEIs are perceived as fundamentally slow to implement proposed changes to a curriculum. This misalignment reflects structural differences between academic and industry priorities.

Administrative processes delay curriculum changes, and individual lecturers are seen as resistant to engaging with industry unless it aligns with their personal research. The third theme indicated that a strong pattern emerged around academics being out of touch with current industry tools and practices. This perception may further widen the gap between academic training and industry expectations. These barriers are interconnected and reinforce systemic challenges, indicating the need for coordinated and structural interventions.

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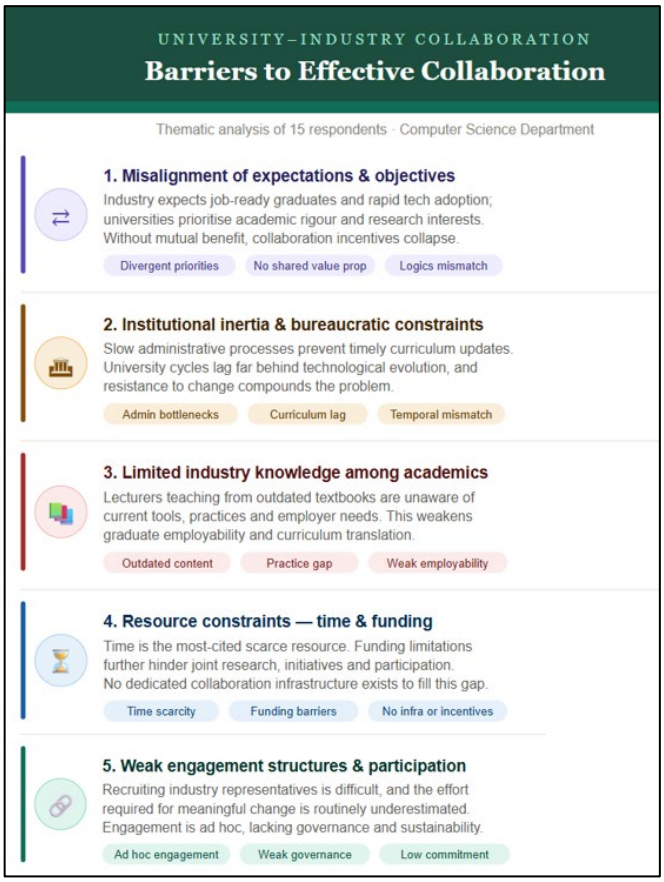


Fig. 3. Barriers to effective communication (Claude generated).

5.5 Skills gap and curriculum alignment

RQ_4 examines the skills industry stakeholders perceive as lacking in recent graduates. The majority (n=13) indicated satisfaction with graduate skill levels, although qualitative responses revealed gaps. Participant 3 indicated, “Graduates lack familiarity with current tools used in production environments. Graduates demonstrated theoretical knowledge but lacked practical, work-ready skills”. Graduates are academically prepared but lack practical, work-ready skills, particularly in applying knowledge within real-world industry contexts (Figure 4). Participant 5 said, “Practical, Job-Ready Technical Skills. Cloud platforms (AWS, Azure, GCP). DevOps practices (CI/CD, containers). System integration (APIs, enterprise systems)”.

The respondents also emphasised the importance of emerging technologies, including AI and data analytics, as well as problem-solving and independent thinking. Participant 8 said, “The use of Gen-AI tools in programming, quality assurance, testing and use of GitHub Co-Pilot”. The most beneficial collaboration types were live industry projects (60%) and guest lectures (53%). Others were internships, research partnerships, and mentorship programmes.

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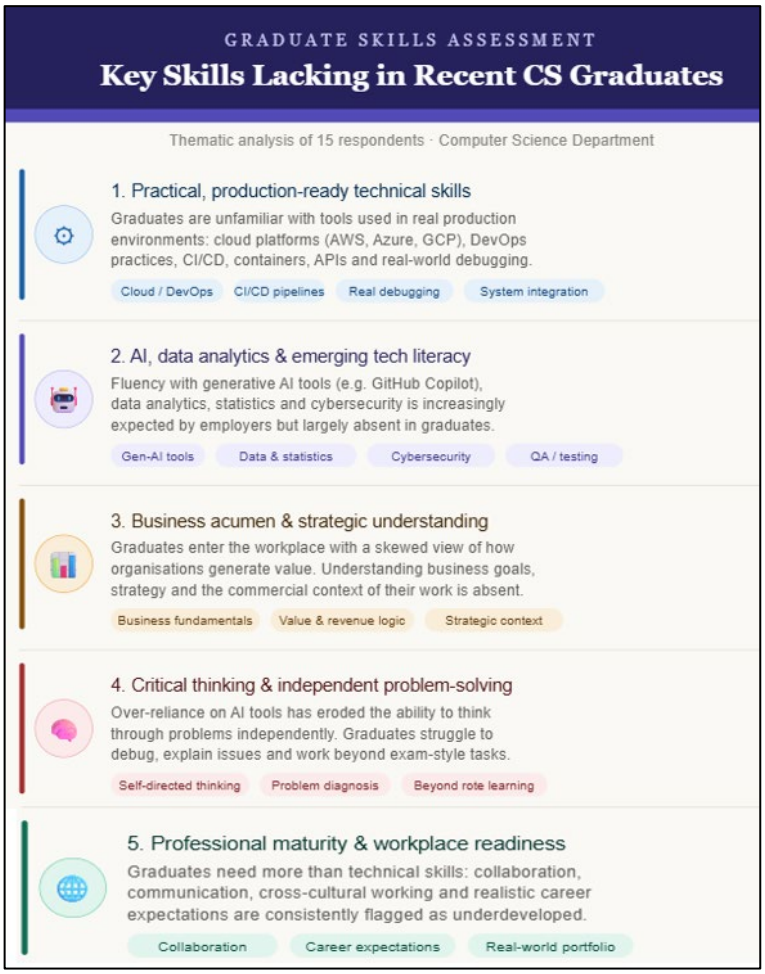


Fig. 4. Key skills lacking in recent graduates (Claude generated).

5.6 Strategic improvement and future direction

RQ_5 examines strategies that can strengthen Industry Advisory Boards and improve university-industry collaboration in rapidly changing technological environments. The thematic analysis for improving IAB functioning is presented in Figure 5. A key finding was that once-a-year meetings are insufficient, and more frequent engagement is required. Respondents recommended shorter cycles, virtual meetings and improved communication between meetings. Respondents also highlighted the need for clearer structure, defined roles and better onboarding processes. More frequent, structured, and flexible engagement supported by clear roles and improved communication is essential to enhance IAB effectiveness.

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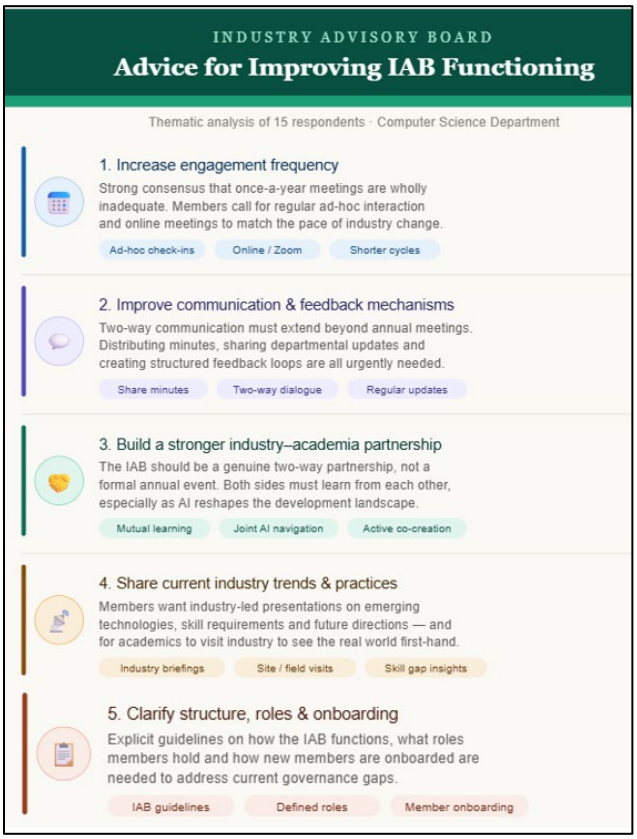


Fig. 5. Advice for improving the functioning of the IAB (Claude generated).

The additional comments industry respondents emphasised were the increasing competition from private institutions and the rapid impact of AI on graduate employability. The most urgent and striking theme in this dataset is that several respondents explicitly named private providers (Eduvos, IIE, STADIO, Academia, MANCOSA and Vega), as rapidly closing the gap with traditional universities on industry relevance and engagement. The respondents further raised concerns about the pace at which AI is transforming what employability looks like, while established frameworks such as the CS2023 ACM guidelines are already regarded as outdated. Participant 6 said, "The CS2023 ACM curricula guidelines do not cater for recent developments in AI. Universities need to adapt their curricula annually". The consensus was not for occasional curriculum reviews but for annual curriculum revision cycles.

The respondents called for industry to be embedded more directly in the learning experience by guest lectures, industry-sponsored projects, and online collaborative formats that bring real-world practice into the curriculum rather than leaving it at the boardroom door. Rapid technological change, particularly driven by AI, and increasing competition from private institutions are intensifying the need for agile, industry-integrated curricula.

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6 Conclusions and future research

The findings indicated that respondents felt that their contributions had an impact on improving curriculum relevance and graduate employability. These findings are consistent with Taylor et al. [9] and Pantanowitz et al. [4], who emphasise the role of industry engagement in enhancing curriculum quality and relevance.

IAB industry members agreed that they should be well-informed about the department's programmes, curriculum, and strategic direction, and that they contributed to maintaining academic standards and programme quality. Some respondents indicated that they did not clearly understand their role and responsibilities as IAB members and that time constraints made it difficult for them to contribute meaningfully. This aligns with Söderlund et al. [11], who highlight the importance of clearly defined roles and structured engagement for effective IAB functioning.

The thematic analysis indicated that IABs provide benefits beyond consultation, supporting curriculum relevance, graduate employability and strategic decision-making. These findings support the work of Evans et al. [13] and Dewantara et al. [10], who identify university–industry collaboration as a driver of improved teaching, research, and employability outcomes. The challenges identified include recruiting relevant members, scheduling meetings and onboarding new members. The AI revolution also emerged as a key challenge. This reflects the observations by Hazrat et al. [15] regarding the increasing demand for adaptable and technologically skilled graduates in rapidly evolving industries.

Industry respondents indicated that the key skills graduates lacked included practical, job-ready technical skills, exposure to emerging technologies such as AI, and experience with real-world projects. Respondents indicated that graduates are academically prepared but not industry-ready. This finding is consistent with Metrôlho et al. [16], who highlight the misalignment between academic training and industry expectations. This highlights the persistent gap between theoretical knowledge and practical application.

The industry respondents further called for more frequent and structured engagement, clearer roles and responsibilities, and improved communication. These recommendations provide practical guidance for improving IAB effectiveness. The findings of this study can assist departments in strengthening university-industry collaboration, particularly through continuous engagement and structured governance. These recommendations align with Lyng and Nortcliffe [7], who emphasise the importance of curriculum agility supported by sustained industry engagement.

From a theoretical perspective, the findings support Stakeholder Theory by demonstrating the importance of aligning the expectations and contributions of academic and industry stakeholders. This reinforces the argument by Freeman [18] that organisational effectiveness depends on stakeholder alignment and value creation.

The findings suggest that universities should strengthen the structure and operation of IABs by clearly defining roles and responsibilities, improving communication, and increasing engagement frequency. Embedding industry collaboration more directly into teaching through live projects and guest lectures can help address the gap between academic preparation and industry readiness. Industry stakeholders should engage more

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consistently to ensure their input translates into meaningful curriculum improvements. This reflects the collaborative model proposed in university-industry partnership literature [2].

The limitations of the study are that the sample size of fifteen respondents is relatively small and limited to IAB members from selected South African universities, which may affect the generalisability of the findings. However, the study was exploratory in nature and targeted a specialised group of participants with direct experience in IAB activities, which supports the relevance of the insights obtained.

Future research will focus on expanding the sample to include more industry members across institutions, including additional stakeholder groups and international comparisons to enhance the generalisability of the findings. This would contribute to addressing the gaps identified in the literature regarding the limited empirical understanding of IAB effectiveness [8].

Disclosure of Interests
None

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The Value of Including a Research Alignment Plan in Honours Project Supervision

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Abstract. Postgraduate students in Computer Science are required to complete a software development project, which is a requirement of the ACM 2023 Computer Science Curriculum. The one-year project requires the development of an artefact, using a software development methodology and associated documentation. Project supervision requires supervisors to advise students on the use of research methods, software development tools and technologies and completing a project write-up. Students are required to draft a project write-up or mini dissertation, documenting the research process, developmental methodology applied and software evaluations, including user evaluations. The Research Alignment Plan (RAP) was specifically developed to assist post-graduate students with planning the outline and structure of their MBA treatise or DBA thesis. The RAP aligns the project title, research problem, research objectives and questions with chapters and chapter deliverables. The aim of the study was to propose a RAP for Honours or 4th year students who were developing an artefact and writing a mini dissertation. In this pilot study, selected Honours students were given an introductory lecture on the use of the RAP. The students drafted a RAP for their projects to include in their project documentation. The students were requested to reflect on their experiences drafting a RAP for their projects. The responses were thematically analysed, and the results of the study indicate that the students clearly found the RAP to be a valuable tool, and the thematic analysis across all five questions provided solid qualitative evidence to support embedding it more formally in an Honours methodology programme. The proposed RAP will assist Honours project supervisors and students in better conceptualising the project documentation.

Keywords: Research Alignment Plan, Honours Projects, Project documentation.

1.1 Introduction

Research is a fundamental driving force behind the advancement of knowledge and the progression of society. It serves as a systematic exploration aimed at uncovering new insights, challenging existing paradigms, and solving complex problems [1]. Basavanthappa [2] adds that research holds a pivotal role in human civilisation because it serves as an instrument to enhance our understanding of the world, providing an intellectual structure for organising, interpreting and applying information. Intellectual

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property, research, technology, software and human capital will be drivers of future long-term economic growth [3].

Research is the foundational engine of the knowledge society, transforming information into innovation, economic growth and societal well-being and includes the combination of both the production and distribution of knowledge [4]. Drucker [5] coined the phrase knowledge society, which he described as "a society in which knowledge becomes the primary driver of economic growth and social development, replacing traditional factors of production". Learning societies, life-long education, etc., are components of a knowledge society [6]. The defining property of a university is its combination of education with research [7].

Universities built on the principles of research training and connected by scientific and cognitive continuity are the key institutions of the knowledge society development [8]. The results of Moyo and Phiri's [9] study suggested that knowledge creation through research and research publications is positively associated with economic growth. They recommend increased investments in basic research to promote knowledge creation. Universities play an important role in restructuring economies in the information age through the generation of new knowledge based on research [10].

Research has always been considered one of the most challenging aspects of being a student [11]. A variety of students at different levels are required to do a research project [12]. Most of these are course-based undergraduate research experiences (CUREs), which are a scalable way to expose students to research and provide opportunities for students to achieve a variety of beneficial outcomes [13]. Graduate programmes, for example, MBAs, are coursework master's programmes that include a component of a research treatise. Research skills are often lacking in these students [13]. Adebisi [14] maintains that developing, maintaining, and sustaining research initiatives can benefit academic institutions, faculty mentors, and students. University students play a key role in the development of a country as future researchers; however, they must become familiar with and understand research activities, as research leads to the development of critical thinking [15].

Students are often uncertain about how best to frame the envisaged significance of their research [16]. One must understand the process by which research is produced to appreciate its value [17]. This is often unclear to those outside of the academy and to students who are about to embark on the research journey. A research process needs to be addressed by standard procedures, which will lead to solutions to the problems [12]. AlQhtani [10] emphasises that it has become necessary for graduate students to produce innovative research that keeps pace with global progress in the field of knowledge management and sharing.

The ACM Computer Science curriculum (CS2023) capstone project requirements specify a one-year project to be completed in a Computer Science student's final year of study. The project is part of project-based learning and skills development and forms an integral part of the broader curricular practices and competency and skills development [18]. Research project supervisors use various tools, techniques and methods to guide and assist students during the research process, including the artefact development process [19].

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Research alignment is the process of linking the research title, research problem, research objectives and research questions with specific chapter deliverables. Research alignment should be taught to novice and postgraduate researchers [20]. Miles [20] (2017a) provided a model and a template, called 'The Alignment Matrix', for developing research alignment in a research study. The Research Alignment Plan (RAP) proposed in this study for Honours Computer Science research project students is based on the RAP developed for MBA students [21]. The RAP links the title of a project to the research problem (RP), research objectives (ROs) and research questions (RQs), specifying which sub-research objectives and sub-research questions will be addressed in a specific chapter and linking the ROs and RQs to chapter deliverables.

The research problem, research objective and questions are discussed in Section 2. A literature review is presented in Section 3, together with a discussion of the RAP for Honours projects. The research methodology is discussed in Section 4, followed by the research findings in Section 5. Conclusions and recommendations of this study, relevant to CS/IS/IT Departments and future work are discussed in Section 6.

2 The Research Problem and Research Objectives

Post-graduate students in departments of Computer Science (CS), Information Systems (IS), and Information Technology (IT) are required to complete a research and software development project in their 4th year of study in South Africa. The RAP for Honours software development project students has recently been developed to assist Honours students with the alignment of the research problem, ROs and RQs for their projects and to be included in the project write-up and documentation. The research objective was to conduct a pilot study and to introduce the RAP in the Honours project development and write-up process, and to determine the students' perceptions of the usefulness of the RAP in Honours. The main research problem addressed in this paper is that the use, effectiveness and value of the RAP from the Honours students' perspective have not been evaluated. The main research question investigated in this study is: How effective is the use of the Honours RAP for students developing an artefact and writing up a treatise or mini dissertation?

3 Literature Review

Research work requires a clear understanding of what is to be done; it requires determination and effort [12]. Research is an essential activity that improves the ability of students to think critically and solve problems, which is an essential life skill [14]. It is essential to understand what research really means – it is about expanding the boundaries of human knowledge [22]. The development of strong research skills for students is not simply an academic requirement but a transformative journey that equips them with the tools to critically analyse and synthesise information and contribute meaningfully to their respective fields [23]. Research methods courses should simplify research so that it can be understandable to the students, and it is challenging for students, because of its complex nature and material [24]. The research process can typically be divided into conceptual, design, planning, empirical, analytical, and dissemination phases [16].

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However, due to a lack of sufficient knowledge regarding the selection of a problem, researchers waste a lot of time in selecting worthless research topics [12]. The structure of research impacts students' ability to work successfully through the research process [25]. The research process is a systematic, cyclical approach to gathering and analysing information to address specific questions or problems. Student challenges with research are a universal problem. Walden University [26] has the following broad guidelines:

- Challenge one: Choosing the right topic- this is the foundation on which everything rests.
- Challenge two: Choosing the right methodology- the methodology that is used comes from the research question, not from your personal preferences for one design or another.
- Challenge three: Finding study participants who will participate.
- Challenge four: Dealing with data.
- Challenge five: Insights from your data.

Supervisors are misleading/misguiding investigators in the process of research because they do not have much training [12]. Supervisors may assume that students know how academic research, writing, and publishing work, or even what it looks like, which can create confusion and frustration for students [25]. Ashrafi-Rizi et al. [27] found that some of the main barriers to doing research were individual barriers, such as a lack of familiarity with research methods and a lack of experience in doing research, amongst others.

Research is a complex skill that requires different techniques to use the database and evaluate the results of research [12]. One of the main challenges arises from the inherent complexity of the research process itself [23]. Daniel's [28] study focused specifically on the problems encountered with the literature review and highlights that several students and early-career academics continue to face challenges when it comes to reading and critically engaging with published work. This is problematic, as effective engagement with academic literature is integral to scholarly and scientific work. The literature review is the heart of your studies [29].

3.1 Academic Theories

Bruner's theoretical framework [30] proposes that learning is an active process in which learners construct new ideas or concepts based on their current/past knowledge. This means effective teaching requires presenting material in a way that allows students to discover principles for themselves. The theory is based on Cognitive structure, which is a mental framework, pattern, or schema that maintains and organises a body of information relating to a particular topic [31]. It is proposed that the RAP becomes the mental structure for students to follow.

3.2 Honours Projects

The ACM Computer Science Curricula 2023 (CS2023) requires project-based learning and a capstone project as part of broader curricular practices and competency and IT skills development [18]. The Honours software development project requires students to identify a problem, preferably industry-based, determine the functional and non-

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functional requirements and develop and evaluate a software artefact. The software development component is linked to a research component, including writing a project write-up or mini dissertation.

3.3 The Honours Project Research Alignment Plan

The Research Alignment Plan (RAP) presented in this paper helps students plan and start their research journey (Table 1). It requires the student to conceptualise the storyline of the study and serves as a guideline for the write-up. The RAP links the title, research problem, research objectives and questions with chapters and chapter deliverables. The approach is granular in that the focus is on detail. The chapters are linked to each component in the process or step required in the research process.

The RAP is based on the thinking that research preparation enhances the research skills, analytical skills, critical thinking as well as cognitive skills of students [32]. The RAP assists with the conceptual, design and planning phases [16]. The RAP is similar to the Alignment Matrix developed by Miles [20]. The RAP has been used by the authors as a tool to assist Master of Business Administration (MBA) and Doctor of Business Administration (DBA) students with their research and treatise or thesis write-up over the past ten years.

In order to introduce the RAP to Honours CS/IS/IT students, the authors proposed an Honours project and drafted a RAP for the project. The Honours project required the development and evaluation of a software application (Honours project) that would incorporate a person's smart watch data into their Medical Health Care Records (MHCR). The RAP drafted by the authors is presented in Table 1. The RAP plan requires that the project title be linked to the research problem, the research objectives and the research questions.

The title of the software development Honours project should be concise, specific, and informative, acting as a concise summary of the research to help readers and search engines locate it. It should highlight the research focus and topic, ideally within 10 words. The research problem must specify the actual problem and be stated in one sentence. A one-sentence research problem must be included in the student's project documentation and specify "What is the actual problem?" The main research objective and the main research question are included in the RAP.

Table 1. RAP example

Title
A Model for Incorporating Smart Watch Data into Medical Health Care Records
Problem Statement
People are increasingly using smart watches, and the data recorded on these devices are not used and integrated into a person's Medical Health Care Records.
Main Research Objective (RO_M)
Propose a model to incorporate the data stored on smart watches into a person's Medical Health Care Records.

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Main Research Question (RQ_M)			
How can smartwatch data be incorporated and stored in a person's medical health care records?			
CHAPTER	**RESEARCH OBJECTIVES**	**RESEARCH QUESTIONS**	**DELIVERABLES**
Chapter Two Literature Review	**RO_1**: Identify wearable devices' functionality and data captured.	**RQ_1**: What functionalities do wearable devices and smart watches provide? **RQ_2**: What data are captured by wearable devices and smart watches?	Smartwatch functionality. Wearable devices and Smartwatch data captured.
	RO_2: Identify the key data stored in a person's medical records.	**RQ_3**: What data are stored in a person's medical health care records?	The key data stored in a person's medical health care records.
Chapter Three Research Methodology and Artefact Design	**RO_3:** Select a suitable research design and research methodology. **RO_4:** Select a suitable software development methodology. **RO_5:** Analyse and design the artefact.	**RQ_4:** What suitable research and software development methodology can be used for the study? **RQ_5:** What should artefact functionality and UX include?	Design Science Research Methodology (DSR), RAP, etc. Functionality specifications and UX designs.
Chapter Four Artefact development and evaluation	**RO_6**: Evaluate artefact implementation and UX.	**RQ_6**: How does the artefact meet system and user functionality and requirements? **RQ_7**: How usable is the artefact?	Functionality and UX evaluations.
Chapter Five Discussion, Conclusions, and Future Research	**RO_m**: Propose a model for incorporating smart watch data into Medical Health Care Records	**RQ_m**: How can smart watch data be incorporated in MHCR?	The proposed model.

Table 1 provides a proposed outline of the chapters to be included in the project write-up. The sub-research objectives and sub-research questions are specified for each chapter. The 'deliverables' of each chapter are 'tangible' outputs, such as a set of functional requirements or user evaluations. Deliverables can be linked to findings, conclusions or, in the case of the example in Table 1, a description of the data stored in a person's medical health care records.

The Honours students were introduced to the RAP in a research orientation lecture on developing a RAP for their research projects. The development of an acceptable RAP was the first requirement or deliverable at the start of the research process. Additionally, the post-graduate students were required to determine the deliverables or outcomes of each of the chapters in their research treatise or thesis. They had to develop the storyline of their treatise or thesis using the RAP. Recognising that research can create barriers to student learning allows supervisors to make meaningful changes [25].

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The students were provided with various graphical examples (Figure 1) to include in their Honours write-up to guide and assist the reader with the layout and structure of the document. The diagram presents the reader with the structure and contents of each chapter, as well as the chapter deliverables. In Figure 1, the authors propose the inclusion of the RAP in the project documentation (Section 1.9).

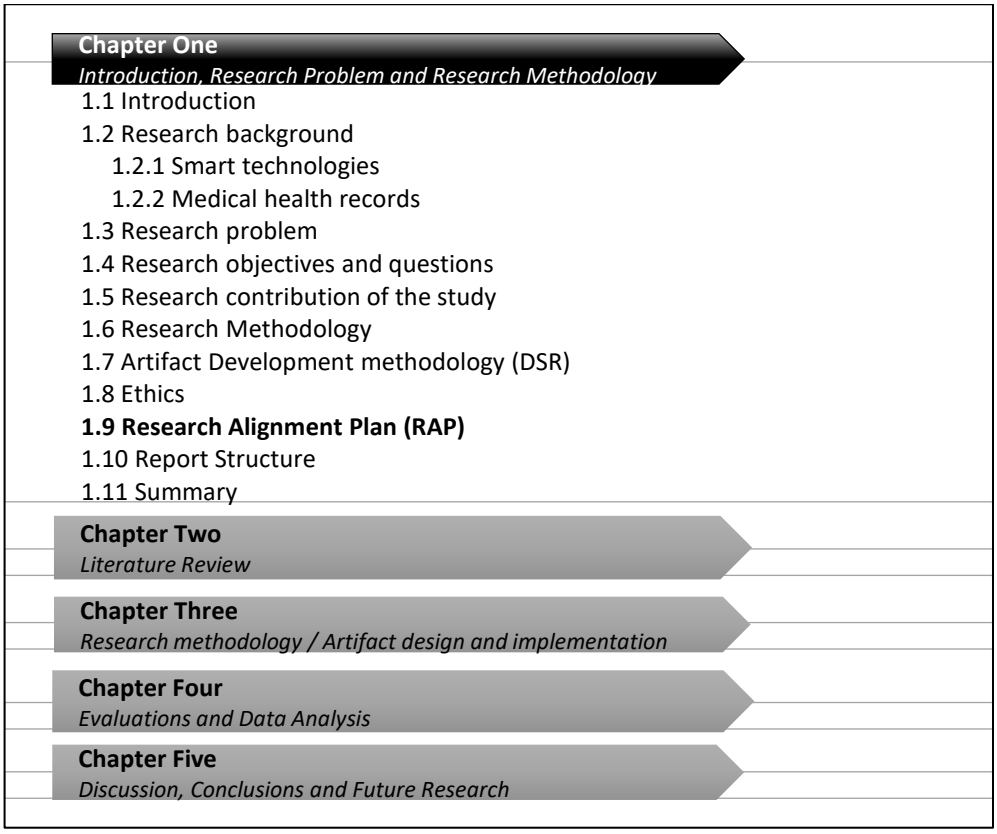


Fig. 1. Chapter One: Structure and chapter layout diagram (Researchers' own Construct)

In the 2-3-hour introductory lecture, the authors explain how to identify a research problem and emphasise the question: Where will you get your data? The student is guided to develop a RAP, identify the appropriate research methodology, generally using the Research Onion developed by Saunders, Lewis and Thornhill [33]. Different application development methodologies were discussed, focusing on DSR. The lecture includes a detailed discussion on conducting a detailed literature review and obtaining the relevant literature resources. The importance of writing styles and the development of a storyline are also explained.

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The use of the following sites to obtain literature is discussed:

- Academia.edu and Google Scholar;
- ResearchGate: Students are advised to join ResearchGate;
- Research journal websites (Elsevier.com; Springer.com; Wiley.com, Emeraldgroup-publishing.com; Taylorandfrancis.com);
- The University library facilities: EbscoHost and the M&D research database on treatises, dissertations and theses; and
- The previous Honours project library in the department.

Other important topics discussed in the lecture include:

- The use of AI;
- Ethics clearance;
- Final timelines (Hand-in date);
- The use of websites to check for plagiarism, Turnitin; and
- The use of academic theories and a conceptual framework.

Finally, the supervisors emphasise two types of research contributions and significance, which must be reported in the final chapter. These include the theoretical contribution and the practical contribution, highlighting the managerial implications of the research findings. Miles [34] indicates three types of significance, which include the theoretical significance, the research significance and the practical significance.

4 Research Methodology

The study followed a quantitative and qualitative research design, and a survey was conducted amongst six Honours students to determine the effectiveness of the use of the Honours RAP to guide their research process, software development, and write-up. Purposive sampling enabled the identification of the respondents, and the survey instrument was a standardised questionnaire used in a previous study [21]. The study was qualitative, and five open-ended questions were asked.

A survey was conducted amongst selected Honours students who attended the introductory lecture and developed a RAP for their project. The evaluation was conducted to determine the effectiveness of the use of the Honours RAP to guide their research process and write-up. Purposive sampling enabled the identification of the respondents, and the survey instrument was a standardised questionnaire used in a previous study [21].

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One five-point Likert-scale question was included in the questionnaire, together with five open-ended questions:

- How did the RAP assist you with your Honours project?
- How did the RAP assist you with identifying deliverables for each chapter?
- How can the RAP be improved?
- How did the introductory lecture to the RAP assist you with your research project?
- Would you recommend that all Honours students use the RAP next year? Please motivate your answer.

The online platform QuestionPro was used to collect the responses. The URL link was sent to the selected Honours students. A total of 6 responses were received. The results were statistically and thematically analysed. The responses to the open-ended questions were analysed using Claude AI.

5 Research Findings and Discussion

The frequency distributions for the items relating to the use of the Honours RAP (n=6) are presented in Table 2. The items included in Table 2 were identified in a study using the RAP for MBA supervision [21]. The responses to the options Strongly Disagree/Disagree and Strongly Agree/ Agree have been combined for reporting purposes.

Table 2. Frequency distributions of items relating to Honours RAP (n=6)

Items	Disagree (n)	Neutral (n)	Agree (n)
Align the project's ROs and RQs	0	1	5
Create a chapter breakdown and content	0	0	6
Assisted with the structure of the project documentation	0	1	5
Provide a framework for the research project	1	1	4
Focus the project and provide guidelines	1	2	3
Clearly identified the research problem	0	0	6
Identified a clear title for the study	0	1	5
Link to the project to a research methodology	0	1	5
The RAP was helpful and informative	0	0	6
Focused the research and the bigger picture of the project	1	1	4
Assisted with the research plan and timelines	0	1	5
Assisted with the structure of the project	0	0	6
Assisted with the contents of chapters	0	0	6
Linked ROs, RQs and the Research Problem with chapters and deliverables	0	0	6
Made me more confident with the focus of the project	0	1	5
Gave me a better understanding of the scope of the project	0	1	5

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The students agreed that the proposed Honours RAP aligned their research problem with the research objectives and questions (Table 1). It, however, did not provide a framework for their total project as students were obligated to comply with the departmental Honours project documentation requirements. The RAP assisted in clearly defining the research problem, assisted with the structure of the project documentation and provided the alignment of the RP, ROs and RQs. The five open-ended research questions were thematically analysed using Claude AI. The four themes identified for each of the five questions were as follows.

5.1 How did the RAP assist you with your Honours project?

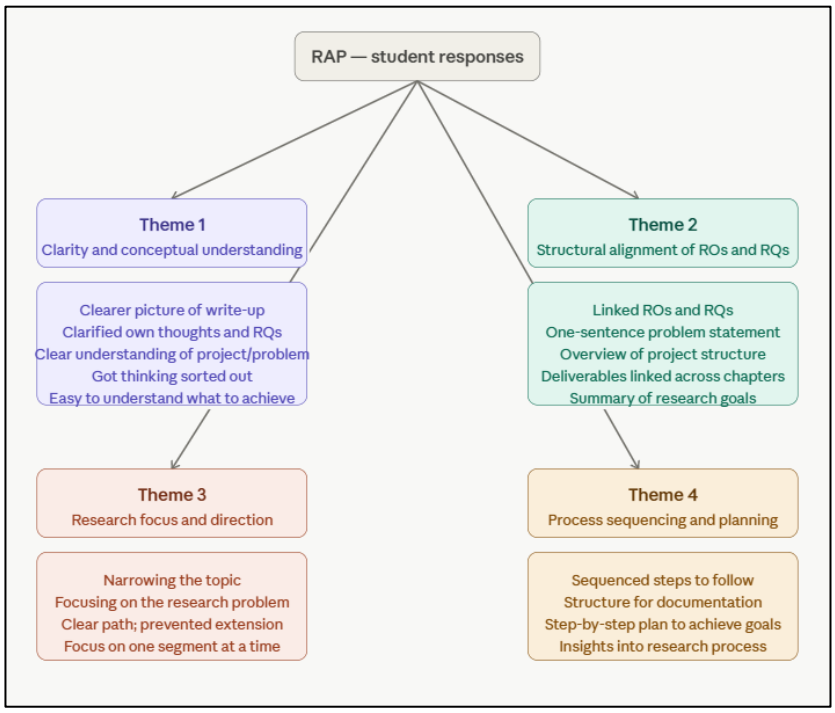


Fig. 2. RAP assist with the Honours project.

Figure 2 graphically presents the four themes identified by Claude AI. The four themes identified for how the RAP assisted with the Honours project are as follows:

Theme 1: Clarity and conceptual understanding. This was the most prominent theme across all the responses. Students described the RAP as helping them gain a clearer picture of their project and what they needed to achieve. Several specifically mentioned clarifying their own thoughts, understanding the research problem, and getting their thinking "sorted out." One student noted it allowed them to summarise their project in a way that was easy to understand.

Theme 2: Structural alignment of research objectives and questions. Multiple students highlighted the RAP's role in explicitly linking research objectives (ROs)

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to research questions (RQs) and connecting those to the overall project structure. One student noted they did not previously know how to formulate a research problem as a single sentence, and the RAP addressed this. Another mentioned that deliverables from one chapter fed into subsequent ones.

Theme 3: Research focus and direction. Students valued the RAP for helping them narrow and focus their topic, and for preventing scope creep or wasted time. One student noted that without it, they likely would have needed an extension due to a lack of direction. Others described it as helping them focus on the actual research problem rather than peripheral concerns.

Theme 4: Process sequencing and project planning. Several students appreciated the RAP as a step-by-step planning tool that explained what needed to be done and in what order. It provided a structured framework for documentation and broke the research down into manageable segments, while keeping the overall objective in view.

One student mentioned the RAP did not help with system requirements, which could be considered as a possible sub-research objective.

5.2 RAP assisted with identifying deliverables for each chapter

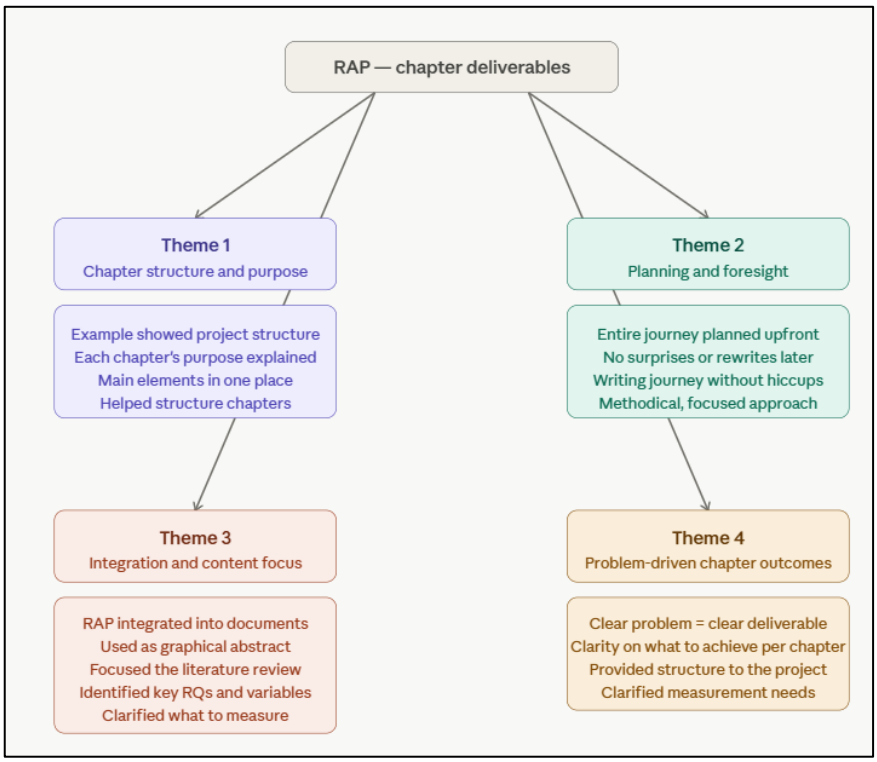


Fig. 3. RAP assists in identifying chapter deliverables.

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Figure 3 graphically presents the four themes identified for chapter deliverables. The four themes identified are as follows:

Theme 1: Chapter structure and purpose. Students found that the RAP, particularly through the worked example, gave them a concrete picture of how an Honours project is structured and what each chapter is meant to accomplish. Having all the key elements consolidated in one place made it easier to understand what each chapter required and how to go about structuring it.

Theme 2: Planning and foresight. A notable strand in the responses was the RAP's value as an upfront planning tool. One student described being forced to think through the entire research journey, including all deliverables, before the study began, which eliminated surprises and rewrites later. This theme captures the RAP's role in de-risking the writing process through early, whole project thinking.

Theme 3: Integration and content focus. One student went further than the others, describing how they integrated the RAP template directly into their project documentation as a graphical abstract. This theme captures responses where the RAP actively shaped the content of chapters, particularly the literature review, by identifying key research questions, variables, and what needed to be measured, thereby keeping the work focused and relevant.

Theme 4: Problem-driven chapter outcomes. Several students described a clear causal logic: once the research problem was well-defined through the RAP, the deliverables for each chapter followed naturally. This theme is distinct from Theme 1 (which is about understanding structure) in that it emphasises the research problem as the anchor from which chapter-level clarity flows.

One student pointed out that while the example was helpful, the research and development methodology section felt underdeveloped. This is a useful comment for refining the proposed RAP template.

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5.3 Proposed RAP Improvements

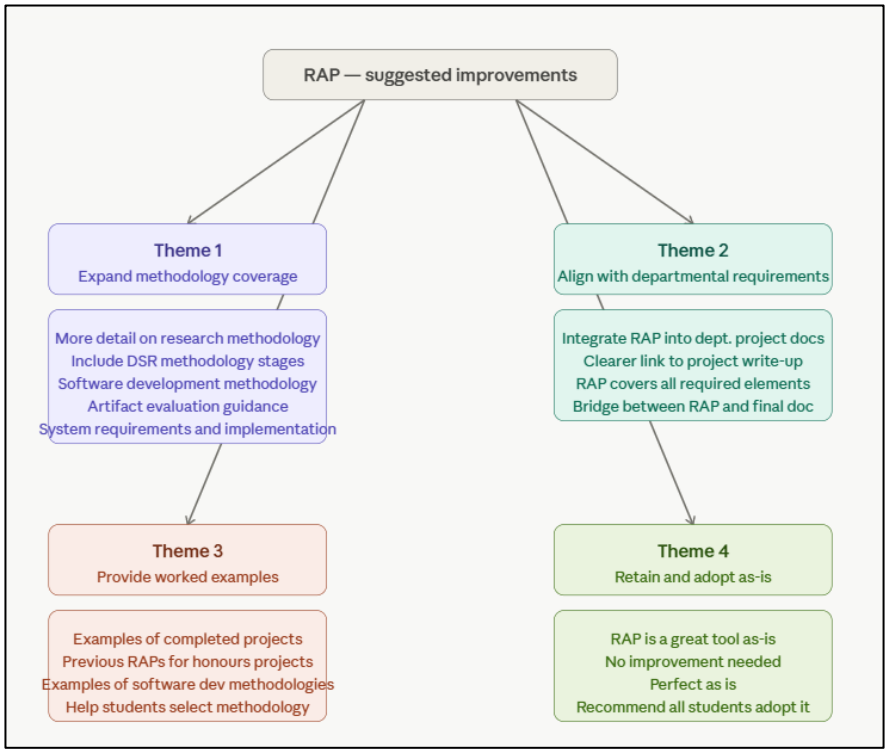


Fig. 4. RAP improvements.

Figure 4 graphically presents the four themes identified for improving the RAP. The four themes identified are as follows:

Theme 1: Expand methodology coverage. The most frequently raised improvement was mentioned by four students. The core ask is for the RAP to go deeper on the research methodology dimension, particularly Design Science Research (DSR) stages, software development methodology options, artefact evaluation, and system requirements and implementation documentation. Students felt the research component was well served, but the technical and methodological side needed more scaffolding.

Theme 2: Align with departmental documentation requirements. Two students independently flagged a disconnect between the RAP and the department's formal project write-up requirements. One student described integrating the RAP into their documents as a graphical abstract, suggesting it has that potential, but noted the link to the official documentation was not made explicit enough. The improvement here is structural: formally embedding the RAP into the department's project documentation framework rather than treating it as a parallel tool.

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Theme 3: Provide worked examples. Students want to see the RAP in action through completed project examples, both finished RAPs from previous cohorts and examples showing different software development methodology choices. This would help students make informed methodological decisions rather than working from a blank template.

Theme 4: Retain and adopt as-is. Three students expressed no desire for changes, with one going so far as to recommend the RAP become mandatory for all students. This is a meaningful counterweight to the improvement themes — it signals that the core value of the RAP is well established and that refinements should build on rather than overhaul what already works.

5.4 Introductory Lecture to the RAP

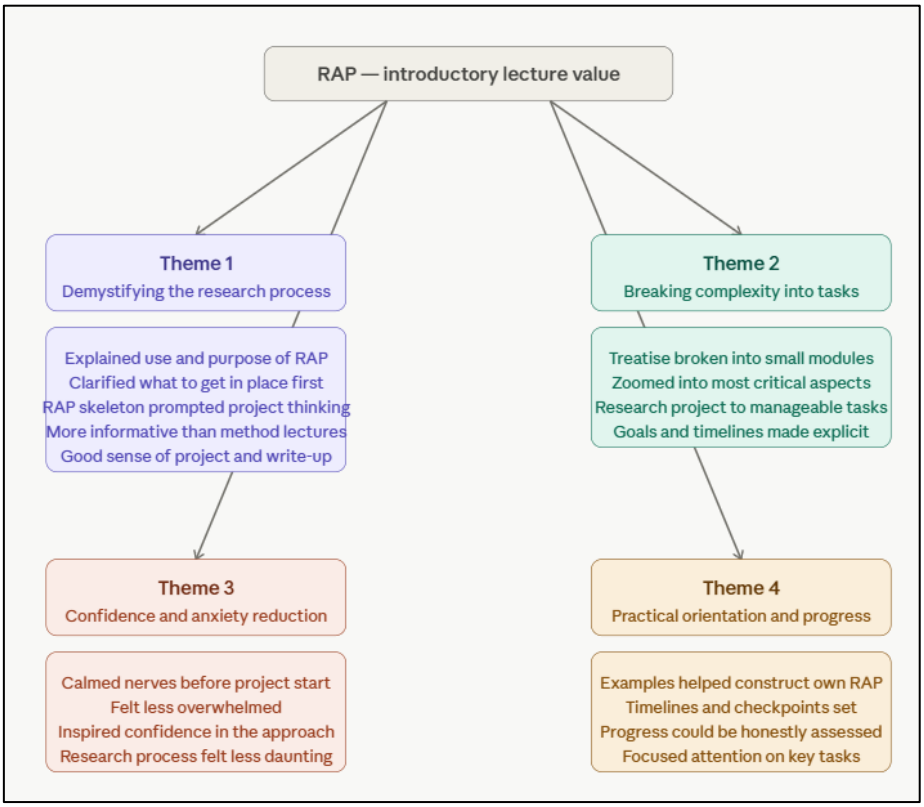


Fig. 5. Introductory lecture.

Figure 5 graphically presents the four themes identified for the introductory lecture, introducing the RAP. The four themes identified are as follows:

Theme 1: Demystifying the research process. Students described the lecture as giving them a clear understanding of what the RAP is, why it exists, and what they needed to have in place before starting their projects. One student made the striking

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observation that they found the RAP lecture more informative than their formal research methodology lectures — suggesting the RAP's applied, project-grounded framing resonates more directly than abstract methodological instruction.

Theme 2: Breaking complexity into manageable tasks. Multiple students used near-identical language to describe this benefit — the lecture helped them decompose what felt like an overwhelming treatise into smaller, discrete modules and tasks. One student described it as a shortcut to zooming in on the most critical aspects of their project. This theme reflects the RAP's scaffolding function, making a large and unfamiliar undertaking feel navigable.

Theme 3: Confidence and anxiety reduction. This is arguably the most affectively significant theme. Several students described the research process as inherently daunting, and the RAP lecture as having a calming, confidence-building effect. One student described feeling less overwhelmed and said the lecture inspired confidence in how to approach the study. This suggests the lecture serves an important pastoral function alongside its academic one — worth recognising explicitly in how you frame and deliver it.

Theme 4: Practical orientation and progress monitoring. Students valued the concrete, actionable outputs of the lecture — particularly the worked examples that helped them construct their own RAPs, and the emphasis on timelines and checkpoints that allowed them to track and honestly assess their own progress. This theme highlights the lecture's role not just in getting students started, but in giving them tools to self-regulate throughout the project.

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5.5 Recommend that all Honours students use the RAP next year.

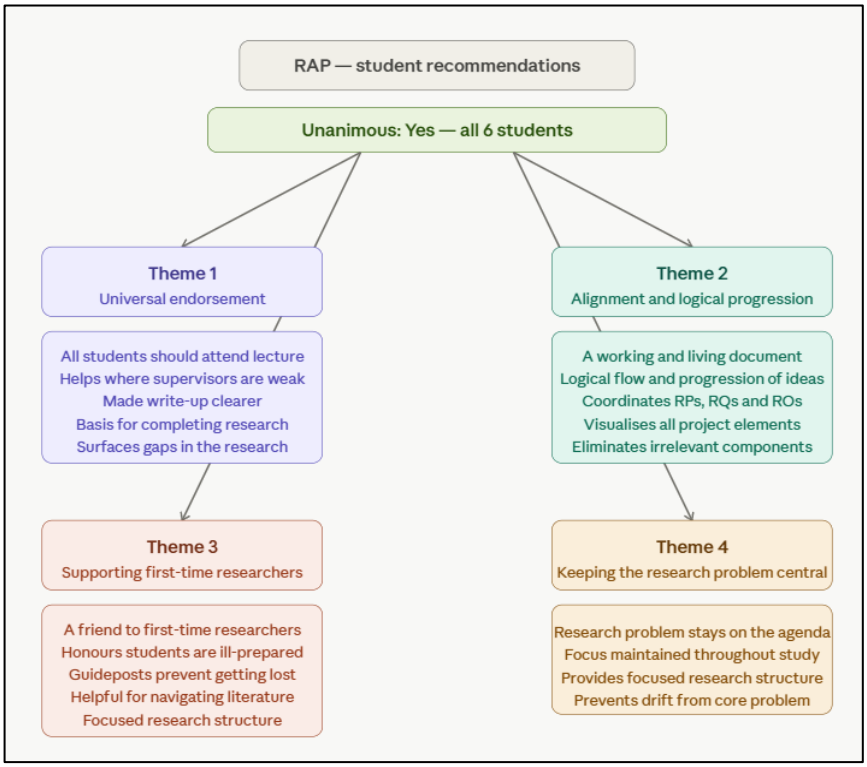


Fig. 6. Recommending the use of the RAP for all Honours students.

Figure 6 graphically presents the four themes identified for recommending whether the RAP must be used by all Honours students. The four themes identified are as follows:

Theme 1: Universal endorsement. Every single student said yes, many emphatically. Beyond the simple affirmation, students articulated concrete reasons: it clarified their write-up, gave them a basis for completing the research, and helped surface gaps early. One particularly noteworthy observation, that the RAP helps where supervisors are weak, suggests students see it as a form of structured academic support that is not always guaranteed from human mentorship alone.

Theme 2: Alignment and logical progression. Several students described the RAP as a living, working document that coordinates the research problem, research questions, and research objectives into a coherent whole. One student articulated this most fully, noting that the RAP enables students to visualise all elements of the project simultaneously while eliminating components that are unnecessary or irrelevant. This theme positions the RAP not just as a planning tool but as an ongoing alignment mechanism throughout the research journey.

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Theme 3: Supporting first-time researchers. Students were candid about the unpreparedness that characterises entry into Honours research, and framed the RAP as uniquely suited to that vulnerability. One student described it as "a friend for first-time researchers", a phrase that captures both its practical utility and its affective role.

Theme 4: Keeping the research problem central. Students described how the RAP functions as a persistent anchor, ensuring the research problem remains the organising principle throughout the project. This is distinct from Theme 2's focus on alignment, here the emphasis is on continuity and discipline over time, preventing drift as the project grows in complexity.

6 Conclusions and Future Research

Universities play a central role in advancing sustainable development through innovative research that improves educational quality and supports the development of human capital [10]. In South Africa, CS/IS/IT departments require Honours students to develop a software development project as part of the formal, curriculum-required modules. The project synthesises what the student has learned throughout the degree. Research and Honours project supervision remains a challenging task for most academics, and post-graduate students generally find the research component of their studies a major challenge. New post-graduate students are generally unfamiliar with research methodologies, and at the Honours level, they complete an individual software development project.

The Research Alignment Plan (RAP) proposed in this paper assists Honours project supervisors and students to start and plan their research journey. The RAP example provided in this paper was used to introduce the RAP to students and assist them in developing their own RAP for their individual projects. The Claude AI final analysis indicated that the five survey questions paint a remarkably consistent picture, namely that the RAP is valued, trusted, and seen as worth embedding permanently in the Honours programme.

Further recommendations from the analysis indicated expanding the research methodology content, integrating it formally into departmental Honours project documentation, and adding more practical examples. The RAP seems to be a valuable tool, and the thematic analysis across all five questions provides solid qualitative evidence to support embedding it more formally in an Honours programme.

The consistency across the responses was particularly striking: students praised the RAP for reducing anxiety, providing structure, and keeping the research problem central. Every respondent recommended it for future cohorts. The improvement suggestions will be included in the future, specifically expanding the research methodology content, aligning the software development methodology, in this case, the Design Science Research methodology, and aligning the RAP with departmental documentation.

The theoretical contribution lies in the evidence from the qualitative results, which confirms that effective teaching requires presenting material in a way that allows students to discover principles for themselves, which aligns with Bruner’s theoretical

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framework [30]. The RAP provides cognitive structure, which is a mental framework, pattern, or schema that maintains and organises a body of information relating to a particular topic [31].

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A Concept Difficulty Analysis of Learning in a Flipped Distributed Systems Course

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Abstract. Flipped classroom models are increasingly adopted in Computer Science education; however, their effectiveness is often evaluated at the overall course level, with limited attention to whether learning gains vary across different concept types. This study examined differences in student performance across concept categories within a flipped classroom implementation of the Processes topic in an undergraduate Distributed Systems course. Drawing on Cognitive Load Theory (CLT), Bloom's revised taxonomy, and the distinction between conceptual and procedural knowledge, the study examined how the complexity of concepts and cognitive demand shaped learning outcomes. The study adopted a classroom inquiry approach involving 71 undergraduate students. The flipped intervention combined lecture slides, pre-recorded lectures, and structured in-class discussion prompts. Student learning was assessed through a 60-item post-topic quiz comprising multiple-choice and fill-in-the-blank questions. Item-level quiz accuracy and response time were analysed across concept categories. Overall quiz performance was moderate at 53%, but substantial variation emerged across concept types. Students performed better on concrete, procedural, and scenario-based concepts such as context switching, fault tolerance, and server scalability. Lower scores and longer response times were observed for more abstract and architecturally complex concepts, including virtualization principles, code migration rationale, and latency-sensitive performance trade-offs. These patterns are consistent with higher cognitive demands associated with conceptually complex content. The findings suggest that a uniform flipped classroom design may not support all concept types equally. The study argues for concept-sensitive flipped pedagogy in Computer Science, in which pre-class materials, in-class activities, and assessments are more deliberately aligned with the cognitive demands of specific subtopics.

Keywords: Flipped classroom, Distributed Systems, concept difficulty, Cognitive Load Theory, Computer Science education.

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1 Introduction

Flipped classroom approaches have become increasingly common in Computer Science education, largely because they are seen as a way to make learning more active and engaging for students [1]. In most flipped classroom models, students are introduced to core material before class, while classroom time is used for discussion, problem-solving, and clarification of difficult ideas. This shift away from traditional lectures is often presented as a more effective way of supporting deeper learning. Research in Science, Technology, Engineering, and Mathematics (STEM) and computing education broadly reflects these advantages, with several studies reporting improvements in student performance, preparation, and overall engagement when flipped approaches are used [2], [3], [4]. However, prior work has also shown that the effectiveness of the Flipped classroom is not uniformly guaranteed across all contexts. Student outcomes are often shaped by engagement with pre-class materials, the quality of in-class support, and the design of learning activities, suggesting that flipped learning should be understood as heterogeneous rather than universally effective [5].

Despite these reported benefits, evaluations of flipped classrooms in Computer Science have often focused on overall course outcomes such as final grades, student satisfaction, or general engagement [1], [6], [7]. While such measures are useful, they can obscure important differences in how students learn specific types of concepts within the same course. Computing topics are not cognitively uniform. Some concepts are concrete, procedural, and readily observable, while others are abstract, layered, and require students to integrate multiple interacting ideas. Existing flipped classroom research has noted that learners do not experience pre-class preparation demands in the same way and that some students may feel overwhelmed by preparatory workload, even when overall learning benefits are reported [8]. These observations suggest that the same flipped classroom structure may support some forms of learning more effectively than others.

This issue is particularly relevant in systems-oriented courses such as Distributed Systems (DS), a subject that requires students to reason about invisible processes, concurrency, communication, resource sharing, and system trade-offs. Topics such as process context, multithreading, virtualization, server organisation, and code migration demand different forms of cognitive processing. Some concepts can be linked to familiar real-world examples and procedural logic, while others require higher levels of abstraction and conceptual transfer. Prior work in DS education has emphasised that the subject is inherently challenging because of the complexity of its concepts and the heterogeneous backgrounds students bring into the course [9]. This suggests that concept chaining in DS can make later topics significantly more difficult when prerequisite concepts are not well understood. These characteristics make DS a useful context for examining whether a uniform flipped classroom design can adequately support conceptually diverse content.

A growing body of flipped classroom research also suggests that uneven learning outcomes may be linked to differences in cognitive demand and knowledge type. Flipped classroom designs are frequently justified through Bloom's revised taxonomy, where lower-order learning is shifted to pre-class activities while higher-order cognitive

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work is reserved for class time [10]. However, evidence suggests that flipped classroom benefits may vary across cognitive outcome categories, with stronger gains often reported for understanding and achievement than for higher-order evaluation tasks [11]. Similarly, the distinction between conceptual and procedural knowledge provides a useful lens for understanding differential learning, as students may succeed in procedural tasks while still struggling with deeper conceptual transfer [12], [13]. These perspectives suggest that concept difficulty and knowledge type are plausible but underexplored sources of variation in flipped classroom effectiveness.

To address this gap, this study examines student performance across concept categories in a flipped classroom implementation of the Processes topic in an undergraduate Distributed Systems course. The flipped intervention drew on a combination of lecture slides, pre-recorded materials, and structured discussion prompts, allowing students to engage with content before class and use contact time for deeper interaction. Student learning was evaluated through a post-topic quiz, with item-level accuracy and response time analysed to explore patterns of concept difficulty.

The study is guided by an integrated analytical framework comprising Cognitive Load Theory (CLT), Bloom's revised taxonomy, and the distinction between conceptual and procedural knowledge. This combination provides a way to examine how differences in concept complexity and cognitive demand shape student performance in a flipped learning context. By focusing on item-level patterns rather than overall course outcomes, the study contributes to the Scholarship of Teaching and Learning (SoTL) by offering a more detailed account of how flipped classrooms support and, in some cases, fail to support different types of learning in Computer Science. This paper addresses the following research questions:

1. How did student performance vary across different concept categories within the flipped classroom implementation of the Processes topic?
2. What patterns of concept difficulty can be identified from item-level quiz accuracy and response-time data?
3. What do these patterns suggest about the suitability of a uniform flipped classroom design for conceptually diverse Distributed Systems content?

The remainder of the paper is organised as follows. Sections 2 and 3 present the literature review and the theoretical framework underpinning the study, respectively. Section 4 describes the course context, flipped classroom intervention, and research design. Section 5 presents the findings, followed by Section 6, which discusses implications for concept-sensitive flipped pedagogy in Computer Science. Section 7 concludes the paper.

2 Literature Review

Learning in flipped classrooms may vary according to the nature of the concepts being taught. In Distributed Systems, concepts differ in abstraction, cognitive demand, and knowledge requirements, yet most flipped classroom studies report outcomes at an overall course level. This section reviews literature on flipped learning, cognitive demand, knowledge types, and systems-level computing education to position the study.

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2.1 Flipped Classroom in Computer Science and STEM Education

Flipped classroom approaches are now widely used in higher education, particularly in STEM fields, where instructors aim to make better use of class time for discussion and problem-solving rather than direct content delivery. A growing body of research, including large-scale meta-analyses, points to positive outcomes, with flipped learning often linked to improvements in student performance, engagement, and preparation [3], [14]. Similar patterns have been observed in computing education, where flipped formats in introductory programming courses have been associated with measurable gains compared to more traditional teaching approaches [4].

Despite these reported benefits, outcomes are not consistent across all contexts. Reviews of flipped classroom research indicate that effectiveness depends on factors such as instructional design, the quality of in-class activities, and engagement with pre-class materials [15]. In Computer Science, student performance has been linked more strongly to engagement with learning resources and instructional support than to attendance alone [16]. These findings suggest that the effectiveness of flipped learning is influenced not only by the model itself but also by how it is implemented.

2.2 Cognitive Demand and Learning in Flipped Classrooms

A key factor underlying variation in flipped classroom outcomes is the level of cognitive demand associated with different learning tasks. Flipped learning is often interpreted through Bloom's Taxonomy, where lower-order tasks such as remembering and understanding are completed before class, while class time is used for higher-order activities like application, analysis, and evaluation [17]. Although this structure is intended to support higher-order learning, research suggests that outcomes may vary depending on the complexity of the tasks involved and the support provided to learners.

These differences point to a potential gap in how complex concepts are supported within standard flipped designs. Tasks that involve abstraction, architectural reasoning, or conceptual transfer may require more structured guidance than is typically provided. Research also shows that the benefits of active learning depend on how activities are organised, with interactive, problem-based approaches generally producing stronger outcomes than more passive or loosely structured formats [18]. In addition, the nature of assessment plays a role: highly structured question formats can restrict opportunities for deeper reasoning, particularly when students are not required to justify or extend their thinking [19]. These findings highlight the need to align instructional design, in-class activities, and assessment approaches with the cognitive demands of the content.

2.3 Conceptual and Procedural Knowledge in Computing Education

Another important dimension in understanding learning in flipped classrooms is the distinction between conceptual and procedural knowledge. In computing education, conceptual knowledge involves understanding principles and relationships, whereas procedural knowledge concerns the ability to execute methods and solve problems. Studies have shown that these forms of knowledge may develop differently, with

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students often able to perform procedural tasks without fully understanding the underlying concepts [20].

Flipped classroom designs often separate these forms of learning across course components. For example, quizzes may be used to reinforce conceptual understanding of content, while in-class problem-solving activities provide scaffolding for procedural skills [21]. However, this separation can lead to imbalances if conceptual understanding is not sufficiently supported, particularly when assessments require transfer or abstraction. Empirical studies have also reported differences in conceptual and procedural learning outcomes in technology-enhanced environments, suggesting that instructional design can influence which type of knowledge is more strongly developed [22].

These findings indicate that analysing learning outcomes at a finer granularity beyond overall performance can reveal important differences in how students engage with different types of knowledge.

2.4 Flipped Learning in Systems-Level Computer Science

Systems-oriented courses, particularly Distributed Systems (DS), present additional challenges that make them a useful context for examining concept-level variation in flipped learning. DS topics require students to reason about concurrency, communication, and system-level interactions that are often not directly observable. Research has highlighted that DS courses are inherently difficult due to the complexity of their concepts and the diverse backgrounds students bring to the classroom [9].

Flipped implementations in systems-level courses have demonstrated potential benefits, including improved learning gains and increased engagement. For example, studies in distributed-systems-related contexts have reported significant improvements between pre- and post-tests following flipped interventions [23]. Similarly, research in operating systems courses has shown improved performance across different assessment formats in flipped settings [24].

At the same time, these studies typically report outcomes at an aggregate level and do not explicitly examine how students perform across different concept categories. Given that systems topics often involve dependencies between concepts, where understanding earlier material is necessary for later topics, it is plausible that learning outcomes may vary significantly depending on concept difficulty and knowledge type.

2.5 Toward Concept-Sensitive Flipped Pedagogy

Recent work has begun to explore how flipped learning designs can be better adapted to support different levels of difficulty and student needs. Studies using learning analytics have demonstrated how item-level performance can be used to identify difficult concepts and trigger targeted instructional interventions [25]. Similarly, approaches such as peer instruction and structured scaffolding have been shown to improve learning outcomes in programming education by aligning activities with task complexity [26].

These approaches reflect a shift toward more differentiated instructional design, where learning activities and supports are tailored to the nature of the content rather than applied uniformly. This is particularly relevant in contexts where task complexity

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varies, as studies have shown that more complex tasks often yield weaker learning gains unless additional scaffolding is provided [6]. In Distributed Systems, where concept dependencies and abstraction levels vary significantly, such differentiation may be critical for supporting effective learning.

3 Theoretical Framework

To examine variation in learning across concept categories, this study adopts an integrated framework that combines Cognitive Load Theory (CLT), Bloom's Taxonomy, and the distinction between conceptual and procedural knowledge. Together, these perspectives provide a basis for interpreting differences in accuracy and response time within a flipped Distributed Systems course.

3.1 Cognitive Load Theory

Understanding how students engage with different types of content requires attention to the cognitive demands placed on them during learning. Cognitive Load Theory provides the primary explanatory lens for this study by focusing on the mental effort required for learning [27]. CLT distinguishes between intrinsic, extraneous, and germane cognitive load, with intrinsic load determined by the inherent complexity of the material and the degree of element interactivity required to understand it [28].

In Distributed Systems, concepts such as virtualization, code migration, and distributed state require learners to coordinate multiple interacting components simultaneously, thereby increasing intrinsic cognitive load. Within a flipped classroom, where students first encounter content independently, managing this complexity may be challenging when instructional support is limited [29].

In this paper, CLT is used to interpret patterns in student performance, particularly the relationship between concept difficulty, accuracy, and response time. Items with lower accuracy and longer response times are interpreted as placing greater demands on learners, especially when they involve complex, interrelated concepts. These patterns are taken as an indication that students may be working under increased cognitive load when engaging with more demanding material.

3.2 Bloom’s Taxonomy

Bloom’s Taxonomy provides a useful lens for examining the cognitive demands of assessment tasks. It distinguishes between different levels of thinking, from basic processes such as remembering and understanding to more complex forms of reasoning, including application, analysis, and evaluation. Within flipped classroom models, this distinction is often used to justify the structure of learning, where foundational tasks are completed before class and more demanding cognitive work is reserved for in-class activities [11], [17].

In this study, quiz items were interpreted in terms of their cognitive demand, enabling an examination of whether student performance differed across levels of thinking.

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Bloom's taxonomy is therefore used to characterise the nature of assessment tasks and to explore whether items associated with lower-order processes are more accessible than those requiring higher-order processes such as abstraction, reasoning, or transfer. This adds perspective for understanding variation in performance across concept categories.

3.3 Conceptual and Procedural Knowledge

A further lens for understanding variation in learning lies in the distinction between conceptual and procedural knowledge. Conceptual knowledge involves understanding underlying principles, relationships, and structures, while procedural knowledge focuses on the ability to carry out steps, apply methods, and solve problems in a structured way [30]. In Computer Science education, both forms are essential, but they often develop differently and may place distinct demands on students [12].

Previous work has shown that students can perform well on procedural tasks while still lacking deeper conceptual understanding, particularly when assessments rely on familiar or well-structured problem types [12], [13]. In flipped classroom settings, pre-class materials may support initial conceptual exposure, while in-class activities provide opportunities to practise procedures [31]. However, topics that require abstraction, integration, or transfer, such as system-level reasoning in Distributed Systems, may require more targeted support than is typically provided.

In this study, concepts within the Processes topic were considered along a conceptual–procedural continuum. Topics such as context switching and thread operations were treated as more procedural, whereas topics such as virtualization, code migration, and system-level trade-offs were viewed as more conceptual. This distinction provides a basis for examining whether performance differences can be linked to the type of knowledge required within the same flipped-learning design.

3.4 Integrated Analytical Framework

More abstract concepts, which require integration of multiple ideas and are associated with higher levels of reasoning, are likely to be more challenging, especially within a uniformly structured flipped design. By contrast, procedural or scenario-based tasks that can be approached step by step may be more readily accessible under the same conditions. This combined framework informs the analysis in this study by guiding the interpretation of item-level performance as shown in Table 1.

Table 1. Integrated Analytical Framework (Bloom × CLT × Knowledge Type)

Bloom's Level	Cognitive Task	Knowledge Type	Instructional Focus (CLT-Aligned)
Remember	Recall, Define	Conceptual(basic) Procedural (facts)	Minimise extraneous load; support encoding
Understand	Explain, Summarise	Conceptual	Manage intrinsic load through clear explanations
Apply	Implement, Use	Procedural	Support schema application; manage intrinsic load

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Analyse	Differentiate, Organise	Conceptual	Increase germane load through guided reasoning
Evaluate	Critique, Judge	Conceptual	Promote schema refinement and higher-order reasoning
Create	Design, Plan	Conceptual and Procedural	Maximise germane load through integration & knowledge construction

The integrated framework also provides a basis for considering whether the flipped design offered sufficient support across different types of content. More broadly, it reinforces the argument that flipped classroom approaches in Computer Science should be sensitive to the characteristics of the concepts being taught, with instructional strategies adapted accordingly rather than applied uniformly.

While each framework offers a useful perspective, none provides a complete explanation of learning on its own. Their combined use is intended to provide a richer interpretation of concept-level variation within the flipped classroom context.

4 Context and Methodology

4.1 Course Context

The study was carried out in an undergraduate Distributed Systems course within a Computer Science programme at a university in South Africa. The course introduces key topics such as processes, communication, synchronization, virtualization, and distributed system architectures. For this study, attention was given to the Processes topic, which covers areas such as process context, multithreading, server organisation, virtualization, code migration, and performance-related considerations.

The study involved a cohort of 71 students. The Processes topic was chosen for analysis because it encompasses procedural tasks, conceptual understanding, and more complex system-level reasoning, making it well-suited for examining differences in how students engage with different types of concepts.

4.2 Flipped Classroom Intervention

A flipped classroom approach was implemented for the Processes topic. The design followed a structured model consisting of pre-class preparation and in-class engagement activities.

For pre-class preparation, students were provided with lecture slides, a chapter from prescribed books, pre-recorded lecture videos and guided discussion prompts. These materials were intended to introduce core concepts and allow students to engage with foundational content at their own pace before class.

During in-class sessions, time was spent discussing key concepts, clarifying difficult topics, and engaging in guided problem-solving using discussion prompts. The discussion prompts were designed to encourage students to engage with both conceptual understanding and applied reasoning. The flipped design aimed to shift lower-order learning outside the classroom and reserve in-class time for deeper engagement, consistent with established flipped classroom practices.

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4.3 Research Design

The study adopted a Scholarship of Teaching and Learning (SoTL) classroom inquiry approach. The study takes a descriptive and analytical approach to examining classroom data, focusing on patterns in student performance, variation across concept categories, and the relationship between concept type and learning outcomes. Attention is given to how students engaged with different parts of the content rather than only to overall achievement.

The analysis is guided by the research questions introduced earlier, with particular emphasis on identifying patterns of concept difficulty within the flipped classroom setting.

4.4 Data Collection

Student learning was assessed using a post-topic quiz consisting of 60 items, including both multiple-choice and fill-in-the-blank questions. Each item was mapped to a single subtopic within the Processes unit based on its primary conceptual focus. A detailed breakdown of item distribution and question types is provided in Table 2.

For each item, two measures were captured: accuracy (correct versus incorrect responses) and response time (time taken to answer). Together, these measures were used to examine both performance and the level of effort associated with different concepts. The quiz was administered under normal course assessment conditions using an online assessment platform. Item-level response times were automatically recorded by the system and used as a proxy measure of cognitive effort.

Table 2. Coding of Quiz Items by Subtopic and Question Type

Subtopic	MCQ Items	FIB Items	Total Items	MCQs	FIB
Process Context & Context Switching	1, 2, 20, 21, 23, 42	—	6	6	0
Threads & Multi-threading	3, 4, 5, 22, 24, 25, 26, 40, 44, 45	52, 58	12	10	2
Virtualization & Containers	6, 7, 27, 28, 39, 47	53, 56, 57	9	6	3
Server Organization	8, 10, 11, 12, 14, 15, 18, 19, 31, 34, 35, 41, 46	59	14	13	1
Code Migration & Mobility	17, 29, 30, 33, 36, 37, 38, 48, 49	60	10	9	1
Performance Considerations	9, 13, 16, 32, 43, 50, 51	54, 55	9	7	2
Total	1–51	52–60	60	51	9

Items were classified according to subtopic, knowledge type, and cognitive demand using the course structure and analytical framework developed for the study. Each item was assigned to a single category based on its dominant conceptual focus. The study focused on concept-level variation rather than differences between assessment formats; therefore, MCQ and fill-in-the-blank items were analysed collectively within their assigned concept categories.

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4.5 Data Analysis

The analysis was conducted at the level of individual quiz items to enable a detailed examination of student performance across concept categories. Each item was considered in relation to its subtopic, the type of knowledge it required (conceptual or procedural), and its level of cognitive demand, interpreted using Bloom's Taxonomy.

Descriptive measures were used to summarise patterns in both accuracy and response time at the item and subtopic levels. Particular attention was given to items with lower accuracy and longer response times, as these were taken to indicate greater difficulty. Comparisons were also made between more structured, procedural tasks and those requiring abstract or integrative reasoning to explore differences in performance across knowledge types. The interpretation of these patterns was informed by the integrated framework, linking observed performance to cognitive load, knowledge type, and cognitive demand.

4.6 Ethical Considerations

The study was part of the course's normal teaching and learning activities. No personally identifiable information was included in the analysis, and all data were anonymised before use. The study did not introduce any additional interventions beyond the standard instructional and assessment practices already in place.

5 Results

5.1 Overall Performance on the Processes Topic

Student performance on the Processes topic was moderate, with an overall mean score of 53% across the 60-item quiz. However, this overall result masked considerable variation between items. While some questions were answered correctly by most students, others had very low success rates.

A similar pattern was observed in response times, with certain items taking noticeably longer to complete. Taken together, these results suggest that students did not experience the topic uniformly but instead faced varying levels of difficulty depending on the concept being assessed.

5.2 Performance by Concept Category

Table 3. Performance by Concept Category

Subtopic	Knowledge Type	Total Items	Mean Accuracy (%)	Mean Response Time (s)
Process Context & Context Switching	Procedural	6	65	38
Threads & Multithreading	Procedural	12	56	44
Virtualization & Containers	Conceptual	9	45	53
Server Organization	Mixed	14	60	41

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Code Migration & Mobility	Conceptual	10	42	57
Performance Considerations	Conceptual	9	36	61

Table 3 summarises the mean accuracy and response time across the concept categories.

Quiz items were grouped into concept categories aligned with the course structure and theoretical framework. Clear differences emerged across categories. Procedural topics, such as process context and threading, achieved higher accuracy and shorter response times, whereas conceptually demanding topics, including virtualization, code migration, and performance considerations, showed lower accuracy and required longer response times. Overall, procedural categories outperformed conceptual categories by approximately 20–30 percentage points. These results indicate that learning in the flipped classroom varied systematically according to concept complexity and knowledge type.

5.3 Item-Level Patterns

Further insight was obtained through item-level analysis. Table 4 presents selected low-performing items.

Table 4. Lowest Performing Items

Item No.	Item Concept	Subtopic	Accuracy (%)	Interpretation
13	Servers across the Internet	Server Organization	3	Requires distributed Reasoning
32	CDN cache purpose	Performance Considerations	10	Abstract system Behaviour
33	Code migration rationale	Code Migration & Mobility	10	Conceptual transfer Required
28	Containers usage	Virtualization & Containers	16	System abstraction
30	Weak vs strong mobility	Code Migration & Mobility	32	Conceptual distinction unclear

In contrast, higher-performing items were largely associated with procedural or scenario-based concepts, including context switching, thread behaviour, and basic server models. These tasks tended to involve sequential reasoning rather than conceptual abstraction.

5.4 Response Time and Cognitive Effort

A consistent relationship was observed between accuracy and response time. Items with lower accuracy were generally associated with longer response times, suggesting increased cognitive effort during problem solving.

Extreme outliers were identified through visual inspection of response-time distributions and removed to improve the interpretability of the relationship between accuracy and response time. After excluding extreme outliers, a clear inverse pattern is observed: items with lower accuracy are associated with longer response times, suggesting increased cognitive effort during problem-solving. Figure 1 illustrates the relationship between item-level accuracy and response time.

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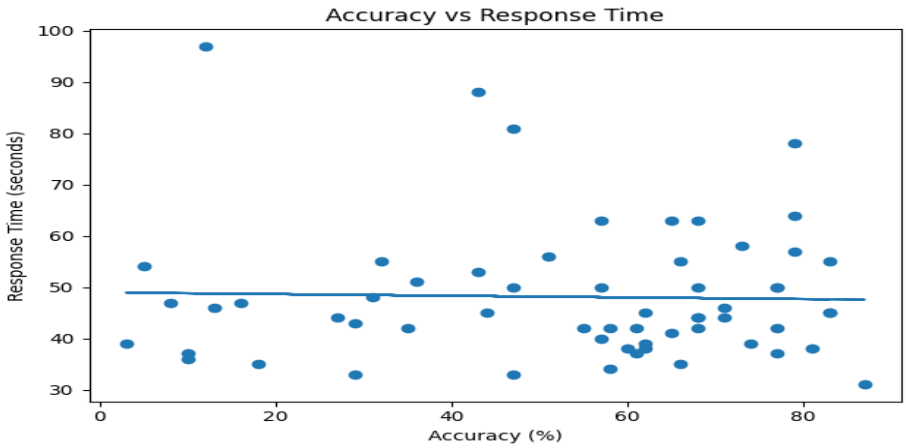


Fig. 1. Accuracy vs Response Time

6 Discussion

6.1 Differential Learning in Flipped Classrooms

The findings indicate that learning within the flipped classroom was not uniform across concept categories. Procedural topics were generally associated with higher accuracy and shorter response times, whereas conceptually demanding topics were associated with lower performance and greater cognitive effort. These results support previous research suggesting that the effectiveness of flipped learning depends not only on the instructional model itself but also on the nature of the content being taught [14], [1]. While many studies report positive outcomes for flipped learning in computing education [3], [4], learning gains are often reported at an aggregate level. The present findings suggest that such measures may conceal important variation between concept types. In Distributed Systems, concepts differ substantially in abstraction, interdependence, and reasoning requirements, which may explain why students responded differently to the same flipped learning environment.

6.2 Concept Difficulty, Cognitive Load and Knowledge Type

The observed differences can be interpreted through the combined lens of Cognitive Load Theory, Bloom's Taxonomy, and conceptual–procedural knowledge. Concepts such as virtualization, code migration, and performance trade-offs require learners to coordinate multiple interacting ideas and reason about behaviours that are not directly observable. These characteristics are associated with increased cognitive demand and may place greater pressure on working memory [28], [29].

The relationship between lower accuracy and longer response times further supports this interpretation. Figure 1 suggests that students invested additional effort in conceptually demanding items yet still experienced difficulty answering them correctly. Similar challenges have been reported in computing education contexts where learners are

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required to engage in abstraction, conceptual transfer, and systems-level reasoning [9], [22].

From a knowledge perspective, the findings also support the distinction between conceptual and procedural learning. Procedural topics such as context switching and thread operations appeared more accessible than topics requiring deeper conceptual understanding. This is consistent with research suggesting that procedural competence and conceptual understanding may develop at different rates [21], [19].

6.3 Implications for Flipped Classroom Design

These findings indicate that the effectiveness of flipped learning is not determined solely by how cognitive tasks are distributed across learning phases. Instead, it depends on how well instructional support aligns with the cognitive demands of the content. Concepts requiring abstraction, integration, and conceptual transfer may require more structured support than is typically provided in a uniform flipped design [25].

This suggests the need for a more concept-sensitive approach to flipped pedagogy. For cognitively demanding topics, instructional strategies such as worked examples, scaffolded activities, guided discussion, and incremental concept integration may be beneficial. Similar approaches have been shown to improve learning outcomes when aligned with task complexity and learner needs [24], [25].

The findings reinforce the view that flipped classroom design should be adapted to the characteristics of the concepts being taught rather than applied uniformly across all content.

6.4 Contribution to SoTL and Computing Education

This study contributes to the Scholarship of Teaching and Learning by demonstrating the value of concept-level analysis in evaluating flipped classroom implementations. Rather than relying solely on overall course outcomes, the study shows how item-level accuracy and response time data can be used to identify differences in concept difficulty and cognitive demand.

Methodologically, combining performance and response-time measures offers a practical approach to examining both learning outcomes and cognitive effort in classroom settings. The findings also extend existing work on flipped learning in Computer Science by highlighting the importance of concept complexity, knowledge type, and cognitive demand as factors influencing learning outcomes.

7 Conclusion

This study examined how students performed across different concept categories in a flipped classroom implementation of the Processes topic in an undergraduate Distributed Systems course. The findings show that student performance was not uniform across concept types, thereby addressing the first research question. Procedural and scenario-based concepts were associated with higher accuracy and shorter response

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times, whereas more abstract and integrative topics were associated with lower accuracy and required greater cognitive effort.

In response to the second research question, item-level analysis revealed clear patterns of concept difficulty. Lower-performing items were consistently associated with longer response times, indicating increased cognitive demand. These patterns were not random but reflected systematic differences linked to concept complexity, knowledge type, and level of cognitive processing.

Regarding the third research question, the results suggest that a uniform flipped-classroom design does not adequately support all forms of learning. While the approach appears effective for procedural and structured tasks, it may be less suited to concepts that require abstraction, integration, and conceptual transfer without additional instructional support.

This study contributes to the Scholarship of Teaching and Learning by demonstrating the value of concept-level analysis in evaluating flipped classroom implementations in Computer Science education. By combining item-level accuracy and response-time data, the study provides a practical approach for identifying difficult concepts and examining cognitive effort within classroom settings. More broadly, the findings support the development of concept-sensitive flipped pedagogy, where instructional strategies are adapted to the complexity and knowledge requirements of specific topics rather than applied uniformly across all content.

The findings should, however, be interpreted within the context of several limitations. The study focused on a single topic within one Distributed Systems course at a single institution, and measures of prior knowledge and engagement with pre-class materials were not available. In addition, item classifications were developed for analytical purposes and were not independently validated. Future research could extend this work by examining multiple topics, courses, and institutions while incorporating learning analytics, measures of prior knowledge, and engagement data. Further studies could strengthen the methodological basis of concept-level analysis through inferential statistical testing, psychometric evaluation of assessment items, and independent coding procedures. Investigating targeted scaffolding strategies for conceptually demanding concepts would also provide valuable insight into the design of more adaptive and concept-sensitive flipped learning environments.

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Integration of Generative AI tools into the Programming Pedagogy: A conceptual framework

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Abstract
Generative Artificial Intelligence (GenAI) is disrupting all professional knowledge domains and higher education, as it presents new opportunities for both teaching and learning. However, concerns regarding the safe and effective integration of these tools into existing curricula have also been expressed by instructors across different fields. These concerns are the ethical perspectives on integrity, as well as the development of cognitive and professional skills needed by students entering a competitive future job market. In response to these gaps, this paper proposes a conceptual framework to guide the integration of GenAI tools into higher education contexts, particularly in programming courses. Drawing on theoretical foundations from the AI-Lab Framework and the Computational Thinking Framework and supported by the ABC Learning Design method, this paper contributes to scholarly work by proposing design principles that enable instructors to utilise GenAI as a structured learning partner that supports meaningful learning outcomes for students. The framework can be adapted and validated across different subject domains to support broader adoption of GenAI tools into teaching practices.

Keywords: Information Systems, programming education, project-based learning, computational thinking

1. INTRODUCTION

Teaching the fundamentals of Information Systems (IS) to non-STEM students presents persistent challenges, particularly in developing computational thinking and problem-solving skills [1, 2]. These challenges are compounded by the growing use of generative AI tools that enable automated code generation, fundamentally reshaping how programming is taught [3, 4].

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Scholars caution that unstructured or tool-driven adoption of GenAI may undermine conceptual understanding and learner agency, highlighting the need for pedagogically grounded frameworks to guide integration into learning activities [5, 6, 7].STEM education refers to education in the disciplines of science, technology, engineering, and mathematics, including computer science [8]. Information Systems is a discipline situated within the STEM domain and focuses on the study of information and Information Systems in business and society. Information Systems courses teach a curriculum involving interacting components between people, technology, data, processes, organisations, and societal contexts. A foundation IS course, in particular, aims to develop students' understanding of core concepts such as hardware, software, and information acquisition, as well as the role of Information Systems in supporting transactional, decisional, and collaborative business processes [9].

From the fields of education, computer science, and Information Systems, scholars have highlighted persistent challenges faced by instructors in developing clear and pedagogically grounded guidelines for the effective integration of GenAI into teaching and learning. Specifically, teaching programming has become challenging as these tools can undermine the learning process. Scholars in programming education have increasingly called on educators to either embrace GenAI tools as a collaborative coding partner or to develop new frameworks or adapt existing ones to support the meaningful application of GenAI across diverse disciplinary contexts [6, 10]. These calls reflect growing concerns that ad hoc or tool-driven adoption of GenAI may undermine conceptual understanding, learner agency, and the development of higher-order thinking skills, particularly in foundational computing and Information Systems education[4, 5, 10].

This research thus aims to propose a conceptual framework for integrating Generative AI tools into the Programming Pedagogy to foster computational thinking. Furthermore, the framework serves as a foundation for formulating design principles that guide instructors in effectively incorporating these pedagogical strategies into the programming curriculum. This paper is structured as follows. The next section reviews related literature on generative AI, pedagogy, and associated theoretical constructs. This is followed by a section that outlines the material and methods adopted to propose the framework, after which the design principles are presented in detail. The final section concludes the paper and discusses practical implications and directions for future research.

2. GENERATIVE AI AND RELATED CONSTRUCTS

Learning theories provide conceptual foundations for understanding how students acquire knowledge, skills, and attitudes, and they inform effective instruction design strategies and assessment practices [11, 12]. These theories are rooted in philosophical paradigms such as behaviourism and cognitivism, which emphasise observable behaviour, and internal cognitive processes. However, contemporary research in education commonly presents constructivist perspectives, which conceptualise learning as an active, socially mediated process of meaning construction [13].

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Constructivism is particularly relevant in Information Systems and computing education contexts, where students integrate conceptual reasoning with practical problem-solving. Prinsloo et al. argue that constructivist pedagogies are well aligned with modern computing education, as they foreground learner agency, collaboration, and reflective practice [10]. Closely associated with constructivism is self-regulated learning, which focuses on learners' capacity to plan, monitor, and evaluate their own learning activities. Zimmerman conceptualises self-regulation as a proactive process in which learners assume responsibility for their learning through goal setting, strategy selection, and reflection. Formative assessment and feedback play a critical role in scaffolding these self-regulatory processes, particularly in complex domains such as programming [14]. Collaborative learning theories further complement this perspective, with pair programming shown to support conceptual understanding, peer explanation, and iterative problem-solving through shared cognitive responsibility [15].

Building on these theoretical foundations, this study adopts the ABC model for conceptualisation of course activities. Young provides a practical learning design toolkit that helped the instructors to identify the learning activities, group the learning activities into threshold concepts that were sequenced to plan for learning activities to embed Gen AI tools [21]. Young positions the ABC Learning Design as a pedagogy-led, non-prescriptive toolkit that supports intentional design of learning activities [16, 17]. In this study, the toolkit is used to conceptualise course activities prior to GenAI integration, ensuring that pedagogical intent guides subsequent AI tool integration.

In addition to learning theories, frameworks that explore GenAI integration into teaching were explored. Recent studies emphasise that unstructured adoption of GenAI tools such as ChatGPT risks undermining learning outcomes, academic integrity, and critical thinking, particularly in programming education [5, 18]. In response, researchers have proposed a range of GenAI integration frameworks that seek to outline instruction guidelines for pedagogy design and use of these tools in the classroom.

Human-centred frameworks such as the FIRST-ADLX framework emphasise accessibility, learner empowerment, and ethical responsibility, positioning AI as a support tool rather than a replacement for learning [6, 19]. Similarly, Kong and Yang propose a human-centred learning and teaching framework that highlights GenAI's role in improving self-regulated learning and domain knowledge construction, particularly in formal educational settings [20]. These approaches align with the Pedagogical-Centered AI (PCAI) perspective, which argues that AI applications must be intentionally designed for educational purposes rather than retrofitted from general technological innovations [22].

Other frameworks adopt a more systemic perspective. The DATS (Developers, Administrators, Teachers, Students) framework, for example, incorporates perspectives from multiple stakeholders, developers, educators, administrators, and learners to support AI adoption within higher education contexts [23]. The IDEE framework structures AI integration around learning outcome identification, determining the appropriate automation levels, ensuring ethical considerations, and evaluating feedback to ensure effectiveness and appropriate redesign of Gen AI to achieve desired outcomes[24].

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Collectively, these scholars argue that effective integration of generative AI requires not only technological adoption but also explicit, pedagogically grounded design to guide its use in education contexts.

This study thus responds directly to this gap by adapting the AI-Lab framework by Dickey to incorporate learning-theoretical foundations, specifically drawing on core principles from the ABC model [6, 17]. By embedding relevant concepts from the adapted frameworks, the study proposes design principles for programming instructors. The first iteration involved crafting initial design principles based on literature. Once these principles were designed, internal feedback was sought through workshops with Information Systems and Computer Science lecturers, during which discussions were held to solicit feedback, including points of confusion and gaps in the framework. Two workshops were held, and in the next iteration, the "conceptualize" concept was added. These workshops were spaces of conception of the guidelines, and at the end of iteration 2, six guidelines were developed.

This study contributes to scholarly work by proposing a conceptual framework for integrating GenAI into teaching, positioning GenAI not merely as a productivity tool, but as a structured learning partner that supports meaningful learning outcomes. The next section outlines the materials and methods adopted to design the proposed conceptual framework.

3. MATERIALS AND METHODS

This exploratory research proposes a conceptual framework and design principles for integrating GenAI into programming education to foster computational thinking (CT). To achieve this, a literature review was conducted and a search in the Scopus and Web of Science databases using a specific search query: TS=(("AI-Lab framework " OR "AI integration") AND ("programming") OR ("computational thinking")NOT "K-12")) AND ((LA==("ENGLISH")) NOT (SILOID==("PPRN") OR DT==("PATENT" OR "CLINICAL TRIAL" OR "BIOGRAPHY" OR "MEETING" OR "UNSPECIFIED" OR "LETTER" OR "NEWS" OR "OTHER" OR "AWARDED GRANT" OR "EDITORIAL MATERIAL") OR DT==("REPORT" OR "RETRACTED PUBLICATION"))).

The initial search retrieved 1,786 papers from Web of Science and 118 from Scopus. After screening, duplicates were removed, and papers in K-12 and secondary education were excluded. Once these were removed, a total of 31 papers were selected. Analysis of these papers resulted in the identification of the AI-Lab and Computational Thinking frameworks, further supported by the ABC Learning Design method [16, 17]. These frameworks were adapted to map specific learning types and activities for meaningful integration of Generative AI (GenAI). Based on the phases, the guidelines are built upon principles from the AI-Lab Framework and the Computational Thinking Framework and are further supported by the ABC Learning Design method [16, 17]. In addition to the literature review, a design-based research (DBR) approach was adopted. Within this approach, design principles are collaboratively developed with input from multiple stakeholders [18].

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In this study, Phase 1 and 2 of the DBR process was conducted to conceptualise the design principles in collaboration with practitioners in the computing discipline. During these workshops, practitioners critically engaged with concepts drawn from the literature and collaborated to design and propose principles for integrating generative AI (GenAI) tools into a programming module. The underlying premise of design research is that theory should be systematically applied to inform and guide the design process, with the ultimate aim of generating both practical solutions and advancing scientific knowledge [25]. In the DBR method, the problems are explored in partnership with individuals who engage with them in their everyday practice, using consultative methods such as participant observation, discussions, interviews, focus groups, and reflective journals or blogs [26, 27]. The DBR method is thus used to conceptualise the types of learning and activities in which GenAI tools can be meaningfully integrated. The proposed conceptual framework is outlined in phases as illustrated in Figure 1.

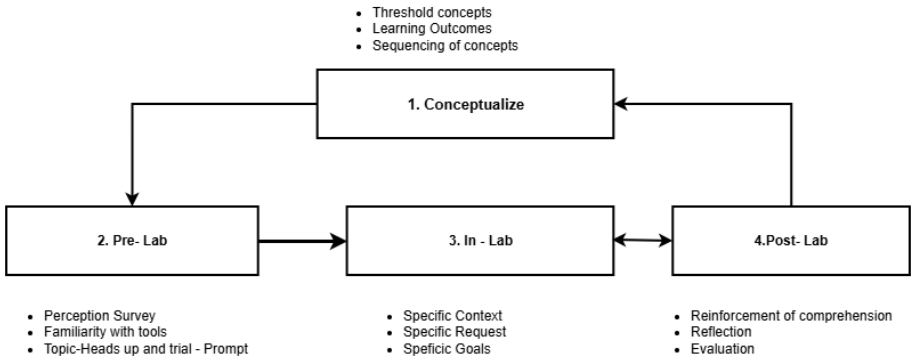


Fig 1: Proposed conceptual framework (adapted from [16 , 17, 32])

The subsequent sections outline the key steps involved in the instruction design process, outlining practical guidelines for a structured learning activity.

The *first stage* in curriculum design is to conceptualize the course or a module within a course. This involves understanding the pedagogy of the subject area and identifying the core concepts that are both central and challenging for learners. Rather than overloading the curriculum with excessive content, an approach that often hinders learning, educators should focus on threshold concepts: key ideas that transform a student's understanding of a subject.

Land describes threshold concepts as "jewels in the curriculum," marking significant shifts in learners' comprehension. Focusing on these concepts helps instructors make strategic decisions about what knowledge is essential and where students are likely to struggle with "troublesome knowledge" [28].

For instance, threshold concepts are identified in Software Engineering to guide curriculum redesign and improve teaching practices, particularly in Software Architecture [29].

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In this stage, educators define clear learning outcomes aligned with the threshold concepts, skills, or competencies students are expected to master by the end of the module. Once identified, these concepts can be sequenced using methods like storyboarding , which visually maps the flow of content and learning activities. This study also adopts the ABC Learning Design method [16, 17] which provides a practical toolkit for integrating blended learning. The Conversational Framework, identifies six types of learning: acquisition, investigation, practice, discussion, collaboration, and production [30, 31]. The ABC toolkit also helps identify where generative AI tools can be effectively integrated either across the entire course or within specific components.

In this research, the design principles were redesign focuses on a coding module. The threshold concepts were re-sequenced and mapped using the ABC learning design cards, as shown in Appendix 1. The instruction design activity is detailed further in the results section.

The *second stage* is Pre-Lab, where the focus is on preparing students to effectively engage with the selected Generative AI (GenAI) tool before in-person lab sessions. This stage begins with the administration of a proficiency and perception survey designed to assess students' current skill levels with GenAI tools, their attitudes towards using these tools in an academic setting, and their perceptions of these tools. The survey can be adapted from established instruments [6] and provides critical guidelines for instruction planning.

Following the analysis of survey responses, students are guided through a series of structured activities designed to build foundational familiarity and confidence with the GenAI tool. Initially, they engage in general prompt-based tasks, particularly when the majority of students demonstrate existing proficiency with the platform. These tasks encourage exploration of the tool's capabilities in a low-stakes environment, helping students become comfortable with its interface and response patterns. As students build confidence, the focus shifts to generating domain-specific prompts aligned with the course's core disciplinary content. For example, in a programming module, students create prompts related to key concepts such as data structures, conditional statements, and polymorphism. These activities foster active engagement with essential course material, encouraging students to use the GenAI tool to seek explanations, clarify definitions, and deepen their understanding of the subject matter.

Throughout the Pre-Lab phase, the instructor ensured alignment between the chosen threshold concepts and the design of activities to maximise the educational value of GenAI integration. The Pre-Lab activities serve as a scaffold, preparing students to utilise the GenAI tool effectively during subsequent in-class lab sessions. Overall, this stage is instrumental in developing students' skills, confidence, and readiness to leverage GenAI tools to achieve enhanced learning outcomes.

The third stage is the In-Class Lab, where students use the output generated during the Pre-Lab activity to compare it with that produced during live classroom prompting.

The session begins with a practice-oriented exercise in which students are instructed to prompt the GenAI tool using clearly defined role and context cues, as emphasised by White [30].

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These two components, role and context, are essential for eliciting high-quality, relevant responses from the GenAI tool. Instructors may adopt various prompting strategies, such as the Persona Pattern, Flipped Interaction Pattern, or Question Refinement Pattern, depending on the disciplinary context.

In this study, the Persona Pattern is used to give the GenAI a specific perspective that guides nature and detail of the output.

An effective prompt should include a clear intent, contextual framing, and a specific request. Adding motivational or situational elements helps structure the GenAI's response. According to Dickey, using direct keywords such as "Give me" and quantifying prompts, such as "a set of 2 examples," can further refine and focus the GenAI output [6]. Instructors play a critical role in this stage. They must guide the prompting process, validate the GenAI-generated responses, and ensure alignment with conceptual learning goals. Verifying the accuracy of responses is vital for maintaining academic rigor. Furthermore, any inconsistencies in the GenAI's output can serve as opportunities for deeper learning. Instructors are encouraged to facilitate interactive discussions, such as think-pair-share, in which students critically analyse discrepancies, explain concepts, and collaboratively reinforce their understanding of the subject matter.

In the *fourth stage*, the instructor serves to reinforce students' comprehension of the concepts while providing instructors with valuable insights into the academic integration of GenAI. As a reflection of the activities completed in the In-class lab, the instructor should design a straightforward worksheet, typically featuring questions based on the lab topic, to be completed as homework. This question should have two parts: one solved using GenAI and the other using traditional methods. This structure helps students understand GenAI's strengths and limitations. Instructors are encouraged to create tasks that leverage GenAI's technical capabilities, such as coding in specific languages, generating test cases, analysing performance, or exploring real-world applications. This worksheet can include domain-specific reflection questions or evaluation questions to highlight the limitations of GenAI tools and their capabilities. These principles from [6, 32] are applied in conjunction with the computational thinking framework outlined by [1]. The proposed principles are discussed in detail in the next section.

4. PROPOSED DESIGN PRINCIPLES

The proposed design principles served as a guide for the threshold concepts of the programming module, as illustrated in a storyboard (appendix 1). The seven-week module introduces students with no prior coding experience to fundamental Python programming. The curriculum is structured around nine core concepts, including data types and variables, conditional execution, functions and modules, iteration, exception handling, file handling, and lists. The design of the storyboard is underpinned by the conceptual framework proposed by Laurillard [30, 31] and expanded by Young [21]. In particular, Young's ABC Learning Design (ABC LD) method is used to identify and sequence learning activities, with Generative AI (GenAI) tools integrated at the overall course level or within specific components. ABC learning design offers educators a practical and reusable approach for planning blended and online learning experiences. This is particularly relevant to the module in question, which adopts a blended learning approach requiring students to complete pre-lab tasks before attending in-class sessions.

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Guideline *1:* Conceptualise the course by defining clear threshold concepts and sequence learning activities to identify the types of learning where GenAI tools are to be integrated within specific course components (module or lesson level).

The conceptualization phase results in the development of a detailed storyboard, as shown in Appendix 1. At this stage, the learning activities can be identified based on the type of knowledge they intend to develop, e.g., Acquisition, collaboration, Discussion, investigation, practice, or knowledge production [21]. The next section outlines the instruction design of the subsequent stages detail, guided by relevant learning theories, computational thinking, and the GenAI-integration framework.

Pre-Lab

The second stage of the instruction design focuses on identifying the key concepts, practices, and perspectives that support student learning. These dimensions are integral to the computational thinking framework and are essential for instructors aiming to foster computational thinking as students engage with learning activities and reflect on their progress. Once the key concepts are identified and the corresponding learning activities that embed computational thinking practices are clearly defined, the instructor prepares students to engage actively with the tasks. This structured sequence ensures that students not only build foundational knowledge but also apply it collaboratively and critically to develop computational thinking capabilities.

Guideline 2: Determine students' GenAI tools proficiency through a survey

A week before the module commences, a proficiency survey should be conducted to assess students' proficiency with GenAI tools. The survey provides a critical diagnostic function of determining students' familiarity and attitudes toward GenAI, which in turn informs the instruction strategy and supports personalisation of the learning experience.

Guideline 3: Familiarise students with GenAI tools through generic prompts on course concepts

Based on the analysis of survey responses, a follow-up can be designed to facilitate a structured exploration of GenAI tools by students. If many students demonstrate proficiency with a specific GenAI platform, that tool is selected to assist students with general prompt-based tasks.

Guideline 4: Familiarise students with GenAI tools through specific subject domain knowledge

lnstructors should also prepare clear guidelines for teaching assistants or the teaching team, including examples of generic and domain-specific prompts. Example: students could be asked to ask general questions, then move to prompts asking questions about the source code. The activity encourages students to engage with key disciplinary concepts actively, helping them construct knowledge and understanding.

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Once students are familiar with the tools, in Step 3 of the pre-lab, you want to intentionally ask the student to Prompt the GenAI on threshold concepts, which will help them think about the meaning of concepts and the logic of syntax. At this point a scenario is introduced to provide a real-world problem to challenge students to decompose and break down the complex scenario into more manageable parts. The Pre-Lab activities are intended to support the instructor in planning and identifying appropriate learning activities for integrating GenAI tools. The following section outlines the In-Class Lab stage, detailing how computational thinking is fostered through hands-on workshops (indicated in purple) conducted in a computer laboratory environment.

In-class Lab

The In-Class Lab stage builds directly on the learning activities completed during the Pre-Lab stage. The primary objective of the lab session is to demonstrate how Generative AI (GenAI) tools can be effectively utilized to develop computational thinking skills and it is guided by the following:

Guideline 5: Practice context-specific subject knowledge by guiding students to make specific requests and prompts aligned with specific learning goals and gather their perspectives to inform instruction design.

Firstly, the instructor should outline the learning objectives for the session, aligned with specific programming concepts. A clear link is established between these objectives and the previous Pre-Lab activities, particularly highlighting how the given scenario can be solved with the support of GenAI tools. To assess students' existing familiarity and comfort with GenAI, a probing question is posed to elicit their general perceptions and usage of the tool. Students are then asked to revisit their Pre-Lab outputs to reinforce continuity between the learning phases.

Secondly, the instructor demonstrates core programming skills such as receiving user input, assigning values to variables, and applying conditional statements to evaluate expressions. Once the traditional coding approach is covered, the instructor demonstrates how to solve the same problem using a GenAI tool, showing its application within a problem-based context.

Guideline :6 Support students in practicing and analysing domain -specific content to construct knowledge, while encouraging them to validate the accuracy and recognize the limitations of GenAI-generated outputs.

At this stage, the instructor facilitates structured practice tasks where students engage with GenAI tools to construct and analyse domain-specific content. The focus is on developing comprehensive prompts and critically evaluating the accuracy and relevance of the generated responses. The instructor introduces worked examples some drawn from student submissions to illustrate both correct and flawed outputs. These examples are used to guide students in validating GenAI-generated content and identifying opportunities for improvement. For instance, students may be asked to revise a prompt to elicit more informative responses, such as adding a request for step-by-step syntax explanations in a coding output.

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Post-Lab

During the post-lab stage, the instructor emphasizes the reinforcement of students' comprehension by encouraging critical reflection on the outputs generated using GenAI tools. Students are prompted to analyze the limitations of GenAI-generated responses by comparing them to conventional coding practices. To facilitate this, learners transition from guided GenAI tasks to hands-on coding within an Integrated Development Environment (IDE). By attempting the same tasks in the IDE, students can assess the accuracy, logic, and effectiveness of GenAI outputs against manually written code. This comparative process fosters critical thinking and reinforces conceptual understanding.

This reflective process concludes with the administration of a Post-Lab Survey, which revisits themes introduced in the Pre-Lab stage. The survey captures students' evolving perceptions of GenAI use in programming and provides valuable feedback for evaluating the instruction design and learning outcomes.

This reflection should be done in a post-lab session, workshop where facilitators will kick-start the reflection. The session will then be concluded by introducing the post-survey. To conclude the cycle, revisit the survey introduced during the Pre-Lab stage. This feedback tool helps assess students' responses to the use of GenAI and provides valuable insights into how their perspectives have developed throughout the learning experience.

5. Conclusion

This study aimed to propose a conceptual framework for integrating Generative AI tools into the Programming Pedagogy to foster computational thinking. Furthermore, the framework serves as a foundation for formulating design principles that guide instructors in effectively incorporating these pedagogical strategies into the programming curriculum. The principles are underpinned by the AI-Integration Framework [32] and the computational thinking dimensions concepts, practices, and perspectives proposed by Brennan and Resnick (2012). The principles are applied to a programming module that is structured into three stages: Pre-Lab, In-Class Lab, and Post-Lab to scaffold the learning process. These stages were designed to introduce key programming concepts, encourage hands-on practice, and develop students' computational thinking perspectives through structured reflection and guided use of GenAI tools.

The principles demonstrate that when GenAI tools are purposefully integrated with pedagogical intent, they can effectively support instructors in designing curricula and pedagogy that help novice programmers understand fundamental programming concepts. Drawing on the AI-Lab framework, the study highlights the importance of clear guidelines to promote the integration of GenAI and encourage engagement with key programming concepts.

Overall, the proposed framework offers guidelines for integrating GenAI into computing education, providing a replicable approach to support the development of computational thinking skills through a problem-based learning approach.

The following design principles outlined in this framework have potential in shaping students' learning experience:

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- **Conceptualization and Sequencing of learning Activities(Guideline 1)**: The use of threshold concepts, a storyboard, and sequenced learning activities enabled clear alignment between instruction goals and the integration points for GenAI tools. This structured planning ensured that AI-supported learning was purposeful and targeted.
- **Diagnostic Survey of GenAI Proficiency (Guideline 2)**: Conducting a pre-module GenAI proficiency survey allowed for tailoring the instruction strategy to students' prior experience with GenAI tools, thereby ensuring differentiated support and inclusive learning design.
- **GenAI tool Familiarisation through Generic Prompts (Guideline 3)**: In early activities, students engaged with GenAI using general prompts on core programming topics. This provided students' entry through low-stake activities while building confidence with GenAI.
- **Domain-Specific Prompts and engagement with GenAI Tools (Guideline 4)**: Students progressed to developing prompts around subject-specific knowledge. The integration of real-world scenarios (e.g., the University Bookshop) prompted students to decompose problems and apply syntax meaningfully, reinforcing logic and abstraction skills.
- **Practice and Prompt Refinement (Guideline 5)**: During in-class labs, students create domain-specific prompts aligned with programming objectives. Iterative refinement and instructor feedback helped students move from superficial outputs to structured, relevant responses, supporting comprehension and engagement with course content.
- **Validation and Analysis of GenAI Outputs (Guideline 6)**: Students critically analyse GenAI responses by comparing them with their own code in the Integrated Development Environment (IDE). Peer comparison, guided debugging, and instructor-led evaluation helped recognise GenAI's limitations and encouraged critical use.
- **Post-Lab Reflection and Comprehension Reinforcement (Guideline 7)**: Reflection sessions enable students to consolidate learning by mapping their GenAI experiences to computational thinking dimensions: abstraction, decomposition, and algorithmic reasoning. The post-survey captured shifts in perception and deepened understanding of both the benefits and limitations of GenAI.

In conclusion, these findings highlight the pedagogical value of integrating Generative AI (GenAI) tools into thoughtfully designed learning activities. The proposed framework fosters active learning, scaffolds the development of computational thinking, and supports formative assessment through prompt-based tasks and reflective practice. Importantly, it also promotes responsible and critical engagement with AI, preparing students not only to write code but to think computationally in learning environments. This research is limited to the development of a conceptual framework and design principles derived from existing literature and feedback obtained from workshops with lecturers in the computing field. These limitations highlight the need for further empirical validation of the conceptual framework in relevant contexts. Furthermore, the

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research can also be conducted as a longitudinal study to better examine the impact of GenAI-integrated pedagogies on computational thinking and student learning outcomes.

While this research focused on proposing a conceptual framework for integrating GenAI in programming pedagogy, its applicability could be extended to other disciplines. Future research should explore how the framework can be adapted and validated across different subject areas to support GenAI integration. Additionally, once adopted, future studies can investigate students' perspectives on its application in programming and its effects on the quality of learning.

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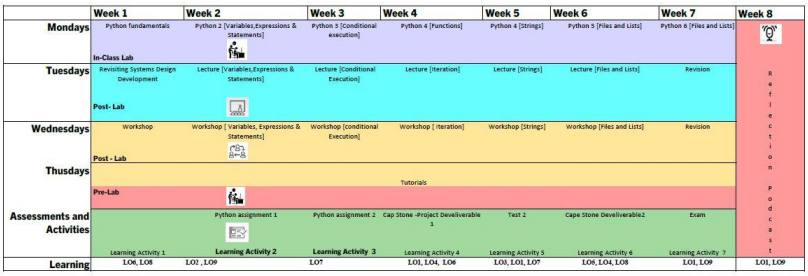
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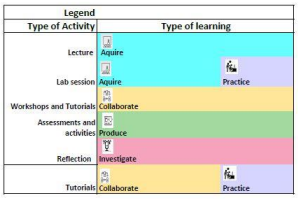
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Appendix 1: Learning activities sequence and alignment with GenAI-Integration tools



	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Mondays	Python fundamentals **In-Class Lab**	Python 2 [Variables,Expressions & Statements]	Python 3 [Conditional execution]	Python 4 [Functions]	Python 4 [Strings]	Python 5 [Files and Lists]	Python 6 [Files and Lists]	
Tuesdays	Revisiting Systems Design Development **Post- Lab**	Lecture [Variables,Expressions & Statements]	Lecture [Conditional Execution]	Lecture [Iteration]	Lecture [Strings]	Lecture [Files and Lists]	Revision	Reflection Podcast
Wednesdays	Workshop **Post - Lab**	Workshop [Variables, Expressions & Statements]	Workshop [conditional Execution]	Workshop [Iteration]	Workshop [Strings]	Workshop [Files and Lists]	Revision	
Thusdays	**Pre-Lab**			Tutorials				
Assessments and Activities	Learning Activity 1	Python assignment 1 **Learning Activity 2**	Python assignment 2 **Learning Activity 3**	Cap Stone -Project Develiverable 1 Learning Activity 4	Test 2 Learning Activity 5	Cape Stone Develiverable2 Learning Activity 6	Exam Learning Activity 7	
Learning	LO6, LO8	LO2 , LO9	LO7	LO1, LO4, LO6	LO3, LO1, LO7	LO5, LO4, LO8	LO1, LO9	LO1, LO9

Learning Outcomes	
LO1	Understand the role of of information systems in organisations society
LO2	Differenciate between data and information their role in business processes and decision-
LO3	Explain the concept of electronic business and various e-business models.
LO4	Manipulate data to produce analytical reports based on business scenerarios by taking into consideration the business intelligence and cloud computing needs or businesses or
LO5	Appreciate the value of information systemss in business and different data sources used in analytics
LO6	Formulate the tasks required when developing an information system and contrast
LO7	Demonstrate through project work, an understanding of the analysis and design of business problems and support decision-making.
LO8	Develop an online business solution using the principles of e-Commerce
LO9	Evaluate the social, organisational, legal and economic context of information systems development



Legend	
Type of Activity	**Type of learning**
Lecture	Aquire
Lab session	Aquire / Practice
Workshops and Tutorials	Collaborate
Assessments and activities	Produce
Reflection	Investigate
Tutorials	Collaborate / Practice

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Aligning South African Undergraduate Computer Science Curricula to Job Requirements and Standard Knowledge Framework using Machine Learning

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Abstract. The development of undergraduate Computer Science curricula that align with both local labour market needs and global standards is essential for national development. In the South African context, concerns have been raised about gaps between existing curricula, 21st-century job requirements, and established curriculum standards. Current design approaches have not adequately addressed the misalignment among standard knowledge frameworks, employer demands, and institutional curricula. This study proposes a machine learning-driven approach to map employment skills to standard knowledge frameworks and apply these mappings to undergraduate curricula. Data were collected from recent South African online job postings, the ACM/IEEE/AAAI Computer Science curriculum guidelines, and Bachelor of Science in Computer Science curricula for three South African universities. Clustering and keyword analysis were used to identify explicit and latent employment skillsets from job postings, followed by topic modelling to refine ambiguous patterns. These skills were then mapped to the standard knowledge framework using structured annotation guidelines. Five machine learning classifiers were evaluated to predict knowledge competence and employment skillsets within the curriculum samples. Results indicate that K-Nearest Neighbour and XGBoost achieved the best performance in knowledge competence and skillset prediction respectively. The analysis also reveals variation in knowledge competence and employment skills across curricula, with a notable absence of customer support skills in two universities, where at least seven of the top 20 key framework features frequently appeared.

Keywords: South Africa, Bachelor's in Computer Science, Curriculum Alignment, Clustering, Classification, Employment Skills, Knowledge Competence.

1 Introduction

The rapid evolution of the global digital economy has intensified the demand for a workforce equipped with both foundational computing knowledge and adaptable, market-relevant skills. As a result, the design of undergraduate Computer Science curricula has become a critical factor in driving innovation, employability, and national development. Universities are increasingly expected to produce graduates who are not only grounded in theoretical principles but also capable of meeting the dynamic needs of

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industry. This expectation is particularly significant in developing contexts, where higher education institutions play a central role in bridging skills gaps and supporting economic growth.

In South Africa, concerns have emerged regarding the extent to which existing undergraduate Computer Science curricula reflect contemporary job market demands [1]. Employers frequently highlight deficiencies in graduates' practical competencies and readiness for the workplace, suggesting a misalignment between academic training, industry expectations, and internationally recognized curriculum standards [2]. While frameworks such as the ACM/IEEE/AAAI Computer Science guidelines [3] provide comprehensive structures for curriculum development, their integration with local employment needs remains inconsistent. Traditional curriculum design approaches [4], often driven by periodic reviews and expert opinion, have struggled to keep pace with rapidly changing skill requirements.

Recent advances in machine learning offer new opportunities to address these challenges through data-driven curriculum design. By leveraging large-scale labour market data and standardized knowledge frameworks, it becomes possible to identify, analyze, and align required skills with academic content. Such approaches enable a more dynamic and evidence-based understanding of curriculum relevance, moving beyond subjective or static methods.

This study builds on these developments by proposing machine learning-based methods to map employment skills to standard knowledge standards, and to evaluate their representation within undergraduate Computer Science curricula. By integrating data from online job postings, globally recognised curriculum guidelines, and institutional curricula from South African universities, the study seeks to provide empirical insights into curriculum alignment and skill coverage.

The findings contribute to knowledge by providing an automated model to build skillsets and knowledge competencies from universities curricula in alignment with job requirements and standard knowledge framework and offering a scalable and adaptable model for curriculum assessment and redesign. The remaining sections are organized into Related Works, Methods, Experimental Set Up, Results and Conclusion.

2 Related Works

A growing body of research has explored the alignment between academic curricula and employer requirements, particularly within the field of Computer Science. Early studies in this area primarily relied on qualitative methods, including surveys and expert consultations to identify skill gaps in graduates [5-7]. While these approaches provided valuable insights, they are subjective and costly. In recent studies, machine learning approaches have been explored.

Chikasha [8] explores the use of artificial intelligence in engineering curriculum quality management, proposing a framework that leverages AI techniques to continuously monitor and improve curriculum relevance. The study demonstrates how intelligent systems can identify gaps between educational outcomes and industry expectations, providing a foundational basis for integrating machine learning into curriculum

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design processes. Karakolis et al. [9] examine the disconnect between technological education and job market requirements, introducing data analytics and decision support system to bridge the gap. Cosine similarity performed better than Jaccard similarity in finding the suitability of users for jobs. Their work emphasizes the role of real-time labour market data in informing curriculum updates and highlights the importance of adaptive educational systems that respond to evolving industry needs. Mason et al. [10] advance this discussion by illustrating how skills taxonomies, combined with machine learning and online job market data, can guide both career decisions and curriculum development. Their approach underscores the value of structured skill frameworks in mapping educational outcomes to employment opportunities, which is particularly relevant for standard knowledge frameworks.

Yahya et al. [11] provide a comprehensive analysis of graduate skills and market demands, advocating for a holistic curriculum development approach. Their findings reveal persistent misalignments between academic training and employer expectations, reinforcing the need for systematic mapping techniques in curriculum design. Xia and Fei [12] introduce a dynamic curriculum adjustment mechanism based on fuzzy reasoning, enabling vocational education systems to adapt continuously to external changes. Their model highlights the potential of intelligent systems to support flexible and responsive curriculum structures, which is critical in fast-evolving fields like computer science. Li [13] presents a machine learning-driven decision support system for evaluating vocational literacy education. By utilizing big data analytics, the study demonstrates how educational institutions can assess and optimize curriculum effectiveness, offering insights into scalable solutions for curriculum alignment. Nouib et al. [14] focus on predicting graduate employability using a hybrid multi-criteria decision-making approach combined with machine learning. Their case study in Morocco illustrates how integrating analytical models with educational data can enhance understanding of employability outcomes and inform curriculum improvements. Gul et al. [15] investigate automated curriculum alignment through machine learning techniques, specifically comparing Support Vector Machines (SVM) and Random Forest (RF) models for course outcome-program outcome mapping. Their findings indicate that machine learning models can significantly improve the accuracy and efficiency of alignment processes in outcome-based education systems.

However, there remains a notable gap in applying these approaches within the South African context, particularly in aligning undergraduate computer science curricula with both employment market requirements and internationally recognized standard knowledge frameworks. This research therefore contributes by proposing a machine learning-based framework that maps job market skill requirements to standardized knowledge domains and institutional curricula within South Africa, addressing both contextual and methodological gaps identified in the literature.

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3 Methods

Machine learning-based methods were extensively explored in the study as presented in the framework in Figure 1. The framework consists of skillset extraction, knowledge-skill mapping and curriculum alignment components. Data collection and preprocessing were performed in each component. The framework is discussed as follows:

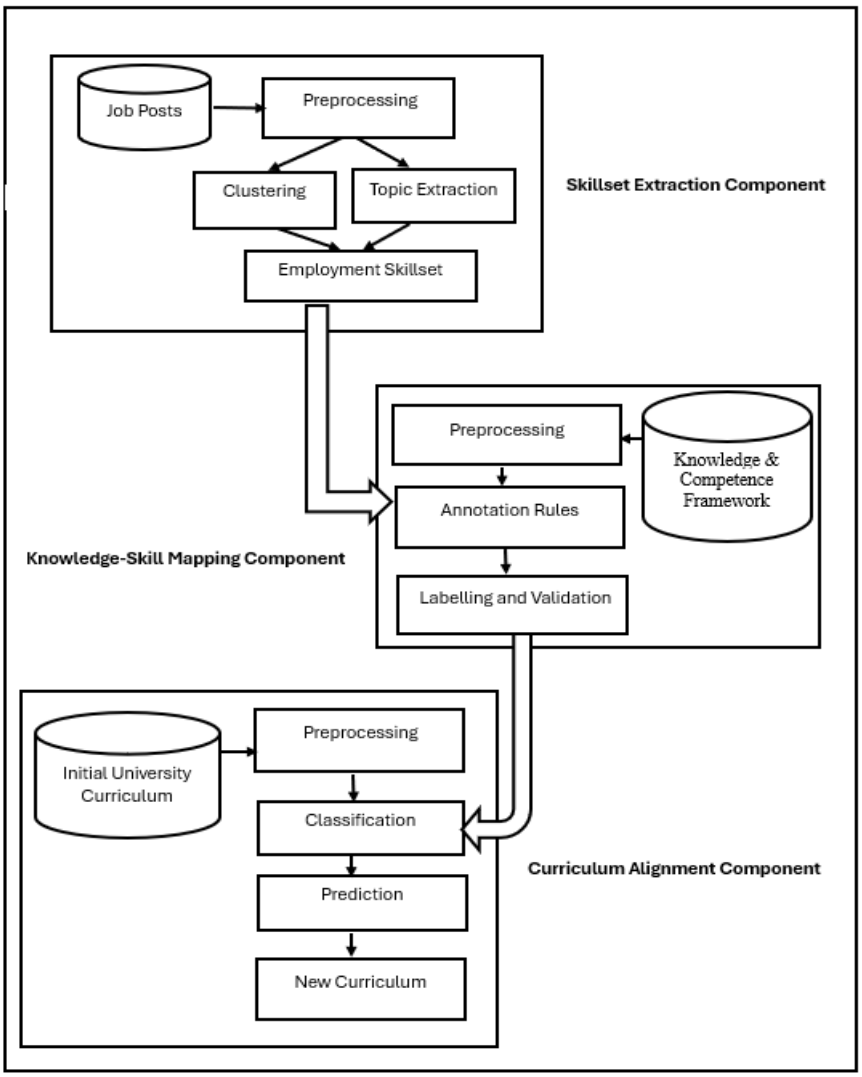


Fig 1. Framework for the Machine Learning-based Approach

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3.1 Data Collection

Three primary data sources were utilized to ensure comprehensive coverage of both industry requirements and academic standards:

(i.) *Job requirement data:* Recent online job postings in South Africa were collected from Linkedin using Apify Proxy [16] to capture current and emerging skill demands, in which bachelor's in computer science was a requirement. The collection was limited to entry-level jobs posted between February 2024 and January 2026. Table 1 presents the data distribution.

Table 1. Data Description for Job Requirements

#Job Posting Count	#Location Count	#Job Title Count	#Sector Count	#Vocabulary Count
144	41	124	46	8,956

(ii.) *Standard knowledge framework:* The 2023 ACM/IEEE/AAAI Computer Science curriculum guidelines [3] were used as a benchmark for knowledge areas and competencies due to their wide acceptability. The knowledge units were limited to the core knowledge and non-mathematical knowledge instances. Table 2 presents the data distribution.

Table 2: Data Description for Knowledge Framework [3]

Knowledge Competence	Knowledge Area	#Knowledge Unit Count
Systems	Architecture and Organization, Operating Systems, Networking and Communication, Parallel and Distributed Computing, System Fundamentals, Data Management, Security	27
Software	Software Development Fundamentals, Algorithm Foundation, Foundation of Programming Languages, Software Engineering	15
Application	Artificial Intelligence, Graphics and Interactive Techniques, Human-Computer Interaction, Specialized Platform Development	11
Cross-Cutting Core Topics	Society, Ethics and the Profession	8

(iii.)*Institutional curricula:* The latest online editions of the Bachelor of Science in Computer Science curricula of three South African universities, anonymized as 'University A', 'University B' and 'University C' were collected. The contents of the core courses (or modules) were used in the study. Table 3 presents the data distribution.

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Table 3. Data Description for Computer Science Curricula

Institution	#Year of Study Count	#Core Course Count	#Vocabulary Count in Course Description
University A	3	16	476
University B	3	16	174
University C	3	14	236

3.2 Data Preprocessing

All textual data from job postings and curriculum documents were cleaned by tokenization, stop word removal, irrelevant word removal, conversion of upper-case words to lower case, and lemmatization. All labels were converted to discrete numerical values.

3.3 Skillset Extraction

Clustering, keyword analysis and topic modelling were used to identify both explicit and latent skillsets required by the employers. The listing is as follows:

(i.) *Clustering technique* was applied to group similar job descriptions and uncover patterns in required skills.

(ii.) *Keyword analysis* was performed to describe the skillset through frequently occurring words.

(iii.) *Topic modelling* was used to refine ambiguous skill patterns and to uncover hidden thematic structures within the job postings.

3.4 Knowledge-Skill Mapping

The extracted skills were systematically aligned with the standard knowledge areas using structured annotation guidelines, which involved:

(i.) *Defining correspondence rules between identified skills and standard knowledge units.* A total of 61 rules, each corresponding to the knowledge units, were developed manually using core contents and learning objectives in relation to the job skills.

(ii.) *Creating a labelled dataset linking job skills to standard curriculum knowledge areas and competencies.* This was carried out by manually assigning job skills to knowledge areas, units and competencies. The annotation was carried out by three experienced university lecturers, who teach undergraduate computer science courses.

(iii.) *Agreement testing to ensure reliability and validation of the mappings.* Cohen Kappa inter-rater agreement was used to measure the reliability of the annotations. In the task, labels were assigned to 61 knowledge units by two lecturers and a substantial agreement score of 0.7379 (0.05 significant level) was

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obtained. In instances where there were disagreements, the contradictory decisions were reviewed by another experienced lecturer.

3.5 Curriculum Alignment

Five standard machine learning classifiers, namely: Logistic Regression (LogReg), Support Vector Machine (SVM), Random Forest (RF), Extreme Gradient Boost (XGB) and K-Nearest Neighbour (KNN) were implemented to evaluate the alignment between curricula and both local employment needs and standard frameworks. They were used to predict knowledge competencies based on curriculum content and identify employment-relevant skillsets embedded within academic curricula. Their performance was compared with cosine similarity [9]. The predictive performance of the classifiers was compared to determine the most effective model for curriculum alignment analysis. Cross-validation technique was employed to ensure robustness and generalizability of the results. Model performance was evaluated using accuracy, precision, recall, and F1-score metrics.

4 Experimental Set Up

Google Colab platform was used for simulation of machine learning models. All codes were written in Python 3.12.13.

4.1 Clustering

K-Means was used for clustering job posts due to its good performance with homogeneous data types and adaptability to large datasets [17]. Thus, Sci-Kit Learn's K-Means module, with number of clusters set at [2 to 5] was used. By analysing the clustering results using Elbow and Silhouette methods, three cluster set up was the best. Table 4 presents the top five most frequent words in each cluster.

Table 4. Top Five Most Frequent Words in the Clusters

#	Cluster 1	Cluster 2	Cluster 3
1	Customer	Support	Experience
2	Solution	System	Team
3	Ensure	Team	Work
4	Support	Experience	Skill
5	Experience	Technical	Support

By analysing the first five to 20 words in the clusters, Cluster 1 explicitly describes Customer Support jobs, Cluster 2 explicitly describes technical system support, while Cluster 3 was vague. Due to the ambiguity of the pattern in Cluster 3, topic modelling was applied to refine the patterns.

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4.2 Topic Modelling

Three topic modelling were evaluated, namely, Latent Dirichlet Allocation (LDA), Top2Vec and BERTopic. Both LDA and BERTopic generated three topics from Cluster 3, while Top2Vec generated two topics. Analysis of the Coherence Scores showed that BERT was better with coherence of 0.41 in contrast to LDA with coherence of 0.36 and Top2Vec with coherence of 0.18. Fig. 2 presents the topics generated by the BERTopic and their top five words.

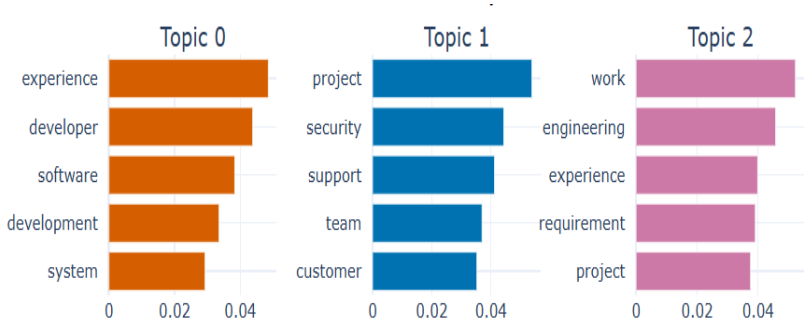


Fig. 2. Job Requirement Distribution by Topics

By analysing the topics, Topic 0 describes Software Development, Topic 1 describes Security Project and Topic 3 describes Project Management and Engineering.

4.3 Knowledge-Skill Mapping

The 61 core knowledge units of the standard knowledge framework [3] were mapped to the South African job skills using knowledge-skill mapping process presented in section 3. Table 5 presents a sample of mapping instances [3].

4.4 Classification

N-grams such as unigram, bigram, and combination of unigram and bigram (unigram + bigram) of the standard knowledge units and South African curricula datasets were first extracted and transformed into term frequency inverse document frequency (TF-IDF) using TFIDF Vectorizer module in Sci-kit Learn [18]. The standard knowledge dataset was split into training and validation samples [training instances = 80%, validation instances = 20%] with random state set to 42. The testing was applied to the South African curricula. The classifiers presented in Table 6 were used for the classification, while cosine similarity [9] was used as the baseline model. The classifiers were optimized using Grid-Search with 5-fold cross validation. The best parameters and scores were used for the validation and prediction.

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Table 5. Sample of mapping instances between South African job skills and the standard knowledge framework [3]

Skill	Knowledge Area	Knowledge Unit	Competence
Project and Engineering Management	Algorithmic Foundation	Foundational Data Structure and Algorithms	Software
Customer Support	Society, Ethics and Profession	Methods for Ethical Analysis	Cross-cutting topics
Technical System Support	Systems Fundamentals	Overview of Computer Systems	Systems
Software Development	Software Development Fundamentals	Fundamental Programming Concepts and Practices	Software
Software Development	Software Developmental Fundamentals	Software Development Practices	Software
Security Project	System Fundamentals	System Security	Systems
Customer Support	Society, Ethics and Profession	Professional Ethics	Cross-cutting topics
Software Development	Foundation of Programming	Language Translation and Execution	Software
Project Management	Data Management	Data Modelling	Systems
Technical Systems Support	Networking and Communications	Networked Applications	Systems

Table 6. Hyperparameter Settings for Classifiers

Classifier	Parameter Setting
LogReg	'penalty' : ['l1','l2'] 'C' : np.logspace(-4, 4, 20) 'solver' : ['liblinear'] 'max_iter' : [10, 50, 100]
SVM	'C': [0.1, 1, 10, 100], 'gamma': [1, 0.1, 0.01, 0.001] 'kernel': ['linear','rbf']
RF	'n_estimators': [100, 200] 'max_depth': [None, 10, 20] 'min_samples_split': [2, 5] 'min_samples_leaf': [1, 2] 'bootstrap': [True, False]
XGB	'max_depth': [3, 5, 7, 9] 'min_child_weight': [1, 2, 3]
KNN	'n_neighbors' : [5,7,9,11,13,15], 'weights' : ['uniform','distance'], 'metric' : ['minkowski','euclidean','manhattan']

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5 Results

Table 7 presents the relation counts between the knowledge competencies of the standard knowledge framework [3] and the skillset. The relation counts indicate completeness of the Application competence in relation to Software Development, Security, Project Management and Engineering and Technical System Support skills. Also, the relation counts indicate completeness of Systems competence in relation to Security, Project Management and Engineering and Technical System Support skills. In terms of Software competence, there were complete relations with Software Development and Project Management and Engineering. The relations of Cross-Cutting core topics to the skillset were the weakest. In general, a completeness score of 0.55 was recorded, demonstrating that the standard knowledge framework aligns slightly with South African job contexts. These suggest that local labour market skills were not the focus of core standard knowledge framework [3].

Table 7. Relation Counts between standard knowledge framework and job skills

Relation	Customer Support	Software Development	Security	Project Management and Engineering	Technical System Support
Systems	0	0	6	5	16
Software	0	7	0	8	0
Application	0	5	4	1	1
Cross-Cutting Core Topics	7	0	1	0	0

In investigating the alignment of the standard knowledge framework with South African labour market needs, the ability of machine learning algorithms to predict skillset and competencies within the standard knowledge framework were examined. Table 8 presents the validation performance of the machine learning classifiers on knowledge competence classification in comparison with cosine similarity (baseline model) [9], while Table 9 presents the validation performance for skillset classification.

The results in Table 8 showed that KNN outperformed other classifiers with accuracy of 0.77, recall of 0.85 and F1-score of 0.79, while RF recorded the best performance in terms of precision. LogReg followed KNN by accuracy of 0.77 and recall of 0.77. SVM recorded the worst performance in contrast to Gul et al. [16] results. Except for SVM, all the classifiers outperformed the baseline model [9] in precision, recall and F1-score. Unigram was better than bigram and unigram+bigram in the LogReg, SVM, RF and KNN models.

The results in Table 9 showed that XGB outperformed other classifiers with accuracy of 0.54, precision of 0.63, recall of 0.53 and F1-score of 0.57, while LogReg followed with slightly higher precision of 0.64. SVM also recorded the worst performance. Except for SVM, all the classifiers outperformed the baseline model [9] in accuracy, precision, recall and F1-score. Unigram was better than bigram and unigram+bigram in all models.

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Table 8. Performance of Classifiers on Knowledge Competence

Classifier	N-gram	Accuracy	Precision	Recall	F1-score
Baseline [9]	Unigram	0.62	0.48	0.56	0.50
LogReg	Unigram	0.77	0.78	0.77	0.73
SVM	Unigram	0.69	0.35	0.44	0.39
RF	Unigram	0.69	**0.82**	0.71	0.74
XGB	Unigram + bigram	0.62	0.73	0.73	0.73
KNN	Unigram	**0.77**	0.76	**0.85**	**0.79**

Table 9. Performance of Classifiers on Skillset

Classifier	N-gram	Accuracy	Precision	Recall	F1-score
Baseline [9]	Unigram	0.38	0.32	0.43	0.36
LogReg	Unigram	0.51	**0.64**	0.48	0.49
SVM	Unigram	0.31	0.30	0.33	0.24
RF	Unigram	0.38	0.54	0.43	0.39
XGB	Unigram	**0.54**	0.63	**0.53**	**0.57**
KNN	Unigram	0.50	0.63	0.50	0.48

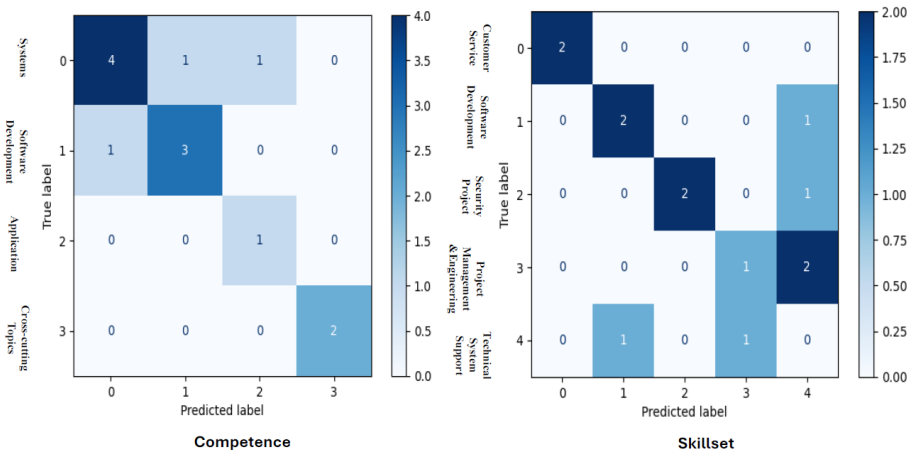


Fig 3. Confusion Matrices for Knowledge Competence and Skillsets

Fig. 3 illustrates the confusion matrices for the predictions of knowledge competencies and job-skills. The competence matrix showed that 100% of Application and Cross-cutting core topic instances were predicted correctly, while 75% and 66.67% of Software Development and Systems instances respectively, were predicted correctly. The skillset matrix showed that 100% of Customer service instances, 66.67% of Software Development and Security Project instances were predicted correctly, while 50% of Technical System Support instances were predicted correctly. The worst performance of 33.33% was recorded in the prediction of Project Management and Engineering instances.

These results indicate that the standard knowledge framework exhibits stronger alignment with knowledge competencies than with job market skills. Nevertheless, job

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market skills such as Customer service are well represented, while Software Development and Security Project are slightly represented in the standard knowledge framework.

Therefore, the aligned competencies and skillsets of the standard knowledge framework were mapped to the curricula of three South African universities using the best classifiers (University A, University B and University C).

In Fig. 4, the distribution charts of knowledge competence and skillsets in the three universities are presented. The skillset chart showed that Software Development, Security Project, Project Management and Engineering, and Technical System Support skillsets are embedded in all the university curricula in different proportions. However, Customer Service only reflects in University C curriculum content.

Also, the knowledge competence of System and Software knowledge areas are well represented in all the curricula, with the highest competence level provided in University A followed by University B. Among the universities, University C curriculum is the only one that captures Cross-cutting core topics.

Furthermore, University C maintains a more balanced distribution of competencies and skills in alignment with the standard knowledge framework, whereas the curricula of University A and University B are skewed toward certain competencies and skills. These findings indicate that the undergraduate Computer Science curriculum of University C is more closely aligned with the global curriculum framework than the curricula of the other universities.

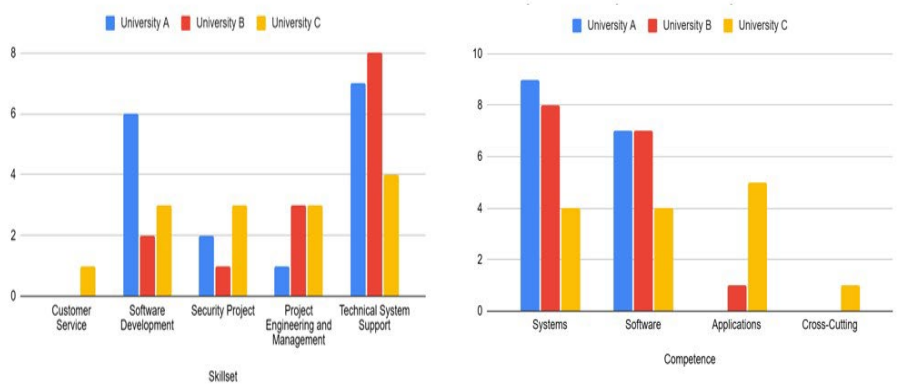


Fig. 4. Skillsets and Knowledge Competencies in University Curricula

The unigram feature comparison in Fig. 5 showed that eight and seven of the top 20 most frequent words in the standard knowledge framework are among top 20 most frequent words in University A and University B curriculum contents, respectively. However, only four in the standard knowledge framework are among top 20 most frequent words in University C curriculum content, which showed poor correlation. In addition, words such as ‘programming’ and ‘data’ are among the first five most frequent words used in all the curriculum contents, which demonstrated the emphasis of South African undergraduate computer science on programming.

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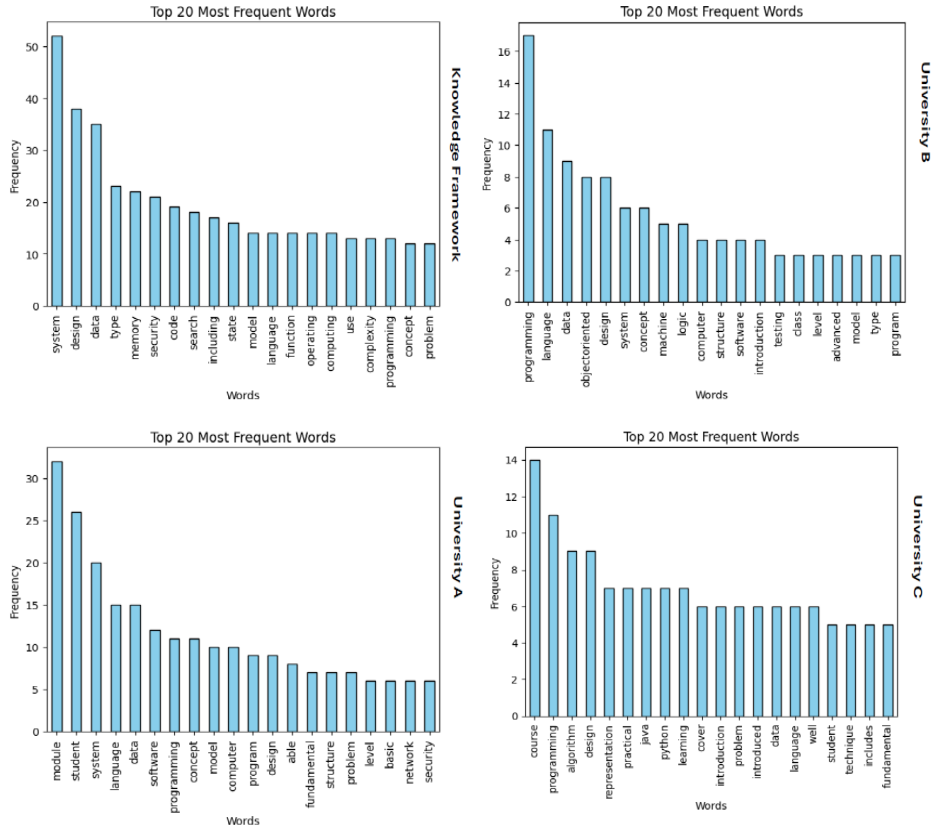


Fig. 5. Top 20 Most Frequent Words in Standard Knowledge and Competence Framework

6 Conclusion

This study set out to address the persistent misalignment between undergraduate Computer Science curricula, labour market demands, and established standard knowledge frameworks within the South African context. By proposing a machine learning-driven framework that integrates job requirement data, curriculum standards, and institutional curricula, the research provides a systematic and data-driven approach to curriculum evaluation and alignment.

The findings demonstrate that machine learning techniques can extract, structure, and map employment-relevant skills to standardized knowledge domains. The combination of clustering, keyword analysis, and topic modelling successfully identified both explicit and latent skillsets from job postings, while the structured annotation process enabled meaningful linkage to knowledge competencies. The machine learning classification results indicated that K-Nearest Neighbour and XGBoost outperformed cosine

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similarity and other classifiers in the prediction of knowledge competencies and employment skill sets, achieving accuracy scores of 0.77 and 0.54, respectively.

Importantly, the analysis reveals notable disparities in the representation of skills and competencies across the examined curricula. While core technical areas such as software development and systems knowledge are well covered in South African curricula, gaps remain in cross-cutting and industry-relevant skills. In particular, the limited presence of customer support skills, applications and cross-cutting core topics in most curricula highlights a critical oversight, given their relevance in real-world computing roles. Additionally, variations in alignment with the standard knowledge framework suggest inconsistencies in curriculum design and emphasis across institutions.

These findings underscore the need for a more dynamic and evidence-based approach to curriculum development. The proposed framework contributes to this objective by offering a scalable and adaptable model for curriculum assessment and redesign.

The major limitations of this study were the homogeneity and relatively small size of the datasets used. Therefore, future work will incorporate larger and more diverse datasets, including data from additional job posting platforms and universities. Furthermore, contextual embeddings and deep learning techniques will be explored to improve predictive performance.

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