

Exploring the Potential of Mindjoy as a Generative AI Socratic Tutor: Fostering 21st-Century
Skills in the General Education Certificate Mathematics Curriculum

by

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Abstract

This qualitative interpretive study explores how Artificial Intelligence (AI) has transformed many aspects of modern life, yet its potential within South Africa's General Education Certificate (GEC) Mathematics curriculum remains largely unexplored. This study aimed to explore the feasibility and potential of Mindjoy, a Socratic generative AI-enabled tutor, within the GEC Mathematics curriculum for Grade 9 learners. The focus was on understanding its impact in fostering key 21st-century skills: collaboration, communication, and critical thinking. This qualitative study is grounded in social constructivism with Laurillard's (2013a) conversational framework as an epistemological approach. Twenty-six learners were asked to complete online questionnaires on online platforms. Furthermore, the study made use of an AI-enabled Socratic learning environment, which exposed learners to two types of mathematics activities. On Day 2 of the study, 26 learners interacted with Mindjoy based on structured mathematical activities. On Day 3 of the study, 10 learners aim to solve problem-based learning activities in collaboration with Mindjoy. Data were coded through thematic inductive analysis using Discourse Analysis and Computational Grounded Theory approaches. Findings revealed that Mindjoy's ability to act as a Socratic tutor is impacted by the ability of the learners to prompt, as well as the type of mathematical activity that learners engage in. The findings highlighted that teachers need to be intentional about their choice of teaching approaches when implementing Socratic AI tutors in mathematics learning. The study illustrated that Socratic questioning delivered by Mindjoy showed potential for guided learning and elicitation; however, its full potential as an AI-powered pedagogical tool revealed limitations, especially during structured mathematical learning concepts. Recommendations include a pre-trained AI mathematics-specific tutor that will probe learners to think critically and help to maintain focus on the learning of mathematics. Additionally, it is recommended that a critical AI literacy framework be implemented to guide both teachers and learners in using AI in a useful, ethical, responsible, and respectful way. Reviewing the current GEC curriculum and assessment framework to include AI literacy as a 21st-century skill was also recommended.

Keywords: 21st-century skills, durable skills, Socratic learning, Socratic questioning, artificial intelligence, generative AI tutoring, discourse analysis, social constructivism, AI roles

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I cannot teach anybody anything. I can only make them think – Socrates.

TABLE OF CONTENTS

1	CHAPTER 1: INTRODUCTION.....	1
1.1	Introduction	1
1.2	Key Concepts and Definitions	3
1.3	The Problem Statement	4
1.4	Research Aims and Objectives.....	4
1.5	Purpose of the Study.....	4
1.6	Research Objectives	5
1.7	Research Questions.....	5
1.8	Significance of the Study	5
1.9	Theoretical Framework	6
1.10	Chapter Summary	6
2	CHAPTER 2: LITERATURE REVIEW	8
2.1	Introduction	8
2.2	Literature Search Methodology	8
2.3	Theoretical Framework	8
	Vygotsky’s Zone of Proximal Development.....	9
	AI as the Digital Knowledgeable Other: A Modern ZPD Framework.....	9
	Laurillard Conversational Framework.....	10
2.4	Problem-Based Learning Reimagined	13
2.5	A time capsule of the history of Artificial Intelligence	13
2.6	AI in Education Today	14
2.7	Integration of AI in Mathematics Education	15
2.8	The art of Socratic questioning	15
2.9	Socratic Learning in Mathematics.....	16
2.10	AI-enabled Socratic tutoring.....	16
2.11	Twenty-first-century Skills	18
	The Importance of 21st Century Skills	19
	Twenty-first-century skills embedded in the global education curriculum.....	19
	Fostering of 21CS within the GEC	20
2.12	Possible roles for generative AI in social learning	25
2.13	Chapter Summary	26
3	CHAPTER 3: METHODOLOGY	27
3.1	Introduction	27

3.2	Research Paragraph: An Interpretive Approach	27
3.3	Research Design	28
3.4	Population and Sampling	28
	Target population.....	28
3.5	Research Procedures	29
	Role of the Researcher.....	31
3.6	Data Collection Methods	31
	Data collection	31
3.7	Data Collection Instruments	30
	Preliminary Questionnaire.....	30
	Chat History (text transcripts).....	30
	Observation	32
	Self-completed questionnaires with Learners	33
3.8	Data Analysis Techniques	34
	NVivo 35	
	Discourse Analysis.....	36
	Computational Grounded Theory	38
	<i>Implementation of the CGT model in this study:</i>	38
3.9	Credibility and Rigour	40
3.10	Ethical Procedures	41
	Application of Wester’s (2011) principles in the study:.....	42
	Respect.....	42
	Autonomy.....	42
	Protection of Vulnerable and Beneficence.....	42
	Justice.....	43
3.11	Ethical Clearance	43
3.12	Chapter Summary	44
4	CHAPTER 4: FINDINGS	45
4.1	Introduction	45
4.2	Socratic Ability of Mindjoy	45
	Research Question 1:	45
	Day 2 – Procedural Mathematical Activity:	48
	Day 3 – Problem-Based Learning Activity.....	52
4.3	Fostering 21st-century skills in an AI-enabled learning space	60
	Research question 2:	60

4.4	AI roles envisioned for mathematics learning	72
4.5	Chapter Summary	77
5	CHAPTER 5: DISCUSSION	78
5.1	Introduction	78
5.2	Overview of the Findings.....	78
	Variance in Socratic Potential	78
	Opportunities and challenges of fostering 21st Century skills	79
5.3	The Domino effect of social constructivism for interpretation of the findings.	83
5.4	Chapter Summary	85
6	CHAPTER 6: RECOMMENDATIONS, LIMITATIONS CONCLUSION	86
6.1	Introduction	86
6.2	Summary of the Study.....	86
6.3	Key findings.....	87
6.4	Implications of the Study	87
6.5	Methodological and Theoretical Value of the Study	88
6.6	Recommendations for Socratic AI-enabled Mathematical Learning.....	90
	Recommendation 1: Guided implementation for teachers on AI in mathematics education.	90
	Recommendation 2: Socratic AI-enabled mathematical tutoring should be intentionally instructed through problem-based learning.	91
	Recommendation 3: Implementing Critical AI literacy into school curriculum	91
6.7	Limitations	91
6.8	Future Research Considerations	92
6.9	Conclusions	93
7	REFERENCES.....	94
8	APPENDICES	112
8.1	Appendix A: Preliminary survey	112
8.2	Appendix B: Creation of the Socratic AI tutor, Lorelei	114
1.1	Appendix C: Chat History Summaries (Day 1-3):	115
8.3	Appendix D: Maths activities/projects handed out to learners	116
8.4	Day 2 Activity	116
8.5	Day 3: Project-Based Activity.....	117
8.6	Appendix E: Self-completed Questionnaire 1	118
8.7	Appendix F: Self-completed Questionnaire 2	123
8.8	Appendix G: Unsaved content detection and notification	125
8.9	Appendix H: Information letter and consent form to parents of participants.	126

8.10	Appendix I: Information letter and consent form to participants.....	129
8.11	Appendix J: Ethics Clearance Application	131
8.12	Appendix K: UCT Ethical Clearance	137
8.13	Appendix M: Mindjoy’s Privacy Policy	139
8.14	Appendix N: Extraction of chat dialogue between researcher and CLAUDE.	145
8.15	Appendix O: Letter from the Principal stating permission from both SMT and SGB	146

List of Figures

Figure 1: The Conversational Framework11

Figure 2: Conversational Framework (Adapted for AI-enabled learning)..... 12

Figure 3: Screenshot of Chat Dialogue..... 31

Figure 4: Screenshot of the question as it appears on the Google form questionnaire..... 33

Figure 5: Screenshot of Chat Dialogue as it appears on Mindjoy 37

Figure 6: Chat transcript for Chat CB4-PBA with reference guide (Mindjoy,2023)..... 59

Figure 7: Learning Cycles of Dialogues on Day 2 80

Figure 8: Learning Cycles of Dialogues on Day 3 82

List of Tables

Table 1: Analytical Tool for exploring Mindjoy's Socratic Questioning ability	18
Table 2: The GEC Observation tool for 21CS	21
Table 3: Tool for exploring the fostering of 21CS within an AI-enabled learning environment..	24
Table 4: AI roles (adapted from Sharples, 2023)	25
Table 5: Data collection period	30
Table 6: The Research Methodology Matrix	33
Table 7: Coding and Sorting of Data	35
Table 8: Fairclough's model for DA: adapted by me.	36
Table 9: Five criteria for judging the quality of qualitative interpretative research (Lincoln, 1995)	41
Table 10: Ethical Procedures.	42
Table 11: Representation of Chat dialogues and Socratic Elements on Days 2 and 3:.....	47
Table 12: Summary of prompts and responses	51
Table 13: Findings on 21CS of Day 2.....	63
Table 14: Findings on 21CS of Day 3.....	71
Table 15: AI roles observed during Day 2	75
Table 16: AI roles observed during day 3	76

List of Abbreviations

21CS: 21st-century Skills

AI: Artificial Intelligence

CAT: Computer Application Technology

CDA: Critical Discourse Analysis

CF: Conversational Framework

CGT: Computational Grounded Theory

COPPA: Children's Online Privacy Protection Act

DA: Discourse Analysis

DBE: Department of Basic Education

FERPA: Family Educational Rights and Privacy Act

GEC: General Education Certificate

GenAI: Generative Artificial Intelligence

NAF: National Assessment Framework

PBL: Problem-Based Learning

POPIA: Protection of Personal Information Act

TVET: Technical and Vocational Education and Training

UCT: University of Cape Town

WCED: Western Cape Education Department

CHAPTER 1: INTRODUCTION

1.1 Introduction

This qualitative interpretive study explores how the rapid advancement of digital technologies, particularly AI, has fundamentally transformed how society operates, communicates, and learns. (Sousa & Rocha, 2019). This digital revolution demands new forms of literacy beyond traditional reading and writing, as learners must now navigate, evaluate, and effectively utilise various digital tools and platforms (Tinmaz et al., 2022). This shift towards digital literacy is crucial for success in a world increasingly reliant on technology. Critical digital literacy has emerged as an essential competency, requiring the ability to access, evaluate, analyse, and critically engage with digital content and technologies within complex information ecosystems (Blau et al., 2020). Digital literacy serves as an umbrella term encompassing competencies for many different technologies (Tinmaz et al., 2022) specific domains of critical literacy are emerging in response to transformative technologies that fundamentally reshape educational practices. One such domain that encapsulates the research of this study is the domain of critical AI literacy, which, according to Pinski et al. (2024) is an individual's comprehensive proficiency to critically assess AI systems, communicate effectively with AI technologies and understand the societal, ethical and practical implications of AI.

The emergence of AI, and specifically the recent breakthroughs in generative AI (GenAI), signals a fundamental transformation in how teaching and learning may be conceptualised and implemented in educational settings (Kasneci et al., 2023). This transformation brings advantages to education, but it also creates challenges (Zheng et al., 2024). One such challenge is that education acknowledges the existence of AI applications and models, but seldom are they aware of the necessity of AI literacy, which should accompany the use of AI in education (Ng et al., 2021). Benvenuti et al. (2023) argue a very valuable point, that AI in education refers to the use of AI technology to enhance teaching and learning, while AI literacy education highlights the importance of educational approaches that equip learners with the knowledge, skills, and values needed to effectively use AI. Recognising the importance of AI literacy underscores the vital role of education in equipping learners with critical competencies like prompt engineering, ethical reasoning, and a holistic understanding of AI's capabilities and limitations as they engage with

these technologies (Benvenuti et al 2023). Learners need to be given hands-on opportunities to solve problems using AI in authentic learning environments to foster skills needed in the 21st century for their work and studies (Ng et al., 2023). Incorporating AI into education is a crucial step toward ensuring that learners are well-equipped to navigate the complexities of the modern workplace, which is significantly different from previous decades, due to the rapid technological change AI has brought upon us (Alekseeva et al., 2021; Mahmud & Wong, 2022).

Within the South African context, the Department of Basic Education (DBE) in South Africa proposed that the General Education Certificate (GEC) forms part of the National Assessment Framework (NAF) to give Grade 9 learners a choice to leave school after ten years (DBE, Republic of South Africa, 2023). One of the pillars of the GEC curriculum framework is to promote the fostering of five key 21st-century skills (21CS). These five skills are stipulated within the GEC guidelines as creativity, critical thinking, communication, collaboration, and metacognition. Each of these five skills comprises sub-skills needed to develop the key skill (Bialik, et al., 2016).

Whilst the GEC framework identifies five 21st-century skills, the DBE mathematics curriculum specifically emphasises only three of the five: critical thinking, communication, and metacognition, having removed creativity and collaboration from the mathematics focus. However, this study focuses on critical thinking, communication, and collaboration, deliberately replacing metacognition with collaboration. This theoretical choice reflects the study's social constructivist foundation, where collaborative knowledge construction through social interaction is fundamental to learning (Vygotsky, 1978). Given that Socratic tutoring emphasises dialogue and collaborative meaning-making between learner and AI tutor, collaboration becomes more directly observable and relevant to this study's AI-mediated learning context than metacognitive processes. Whilst metacognition remains important in mathematics learning, the focus on collaboration better aligns with both the theoretical framework and the interactive nature of AI tutoring platforms.

Unfortunately, there seems to be a gap in adequately creating a learning environment for the fostering of 21CS in a Grade 9 Mathematics classroom and making the learning environment relevant for the effective fostering of 21CS. Bailik et al. (2016) argue that both the observation of the learning process and the product of a learner's learning activities should inform the conclusion of learning outcomes. The current GEC curriculum model's exclusive focus on learning products reveals a gap, overlooking Bailik et al's. (2016) crucial emphasis on the importance of observing

the entire process of 21CS development, which should probably also include digital literacies (Carretero et al., 2017)

1.2 Key Concepts and Definitions

This study draws upon several interconnected concepts that require clarification to establish a common understanding:

21st-Century Skills represent competencies deemed essential for success in contemporary society, specifically referring to the five skills identified in the GEC framework: creativity, critical thinking, communication, collaboration, and metacognition (Bailik et al., 2016)). Each skill comprises sub-skills that collectively contribute to learners' capacity to engage with complex, technology-mediated environments.

Critical AI Literacy encompasses an individual's comprehensive proficiency to critically assess AI systems, communicate effectively with AI technologies and understand the societal, ethical and practical implications of AI (Pinski et al., 2024). This extends beyond mere technical competency to include critical engagement with AI's role in society and education.

Digital Literacy vs. Digital Literacies: While digital literacy serves as an umbrella term encompassing competencies for various technologies (Tinmaz et al., 2022), digital literacies acknowledge multiple, situated practices of meaning-making with digital tools (Carretero et al., 2017). This distinction reflects the ongoing scholarly debate between decontextualised skills approaches and situated literacy perspectives.

Socratic Tutoring refers to an AI-enabled pedagogical approach that employs strategic questioning to guide learners toward understanding, rather than providing direct answers (Benvenuti et al., 2023). This methodology emphasises the learning process over content delivery.

Generative AI (GenAI) encompasses AI systems capable of creating content and engaging in conversational interactions, offering new possibilities for personalised, interactive learning experiences in educational contexts (Bauschard & Quidwai, 2023).

These concepts interconnect within mathematics education through their shared emphasis on process-oriented, technology-enhanced learning that prepares learners for an AI-integrated future.

1.3 The Problem Statement

The current GEC assessment strategy for measuring and observing 21CS development in Grade 9 Mathematics reveals a limited focus on considering the 21CS that the learner might be using to solve or understand mathematical concepts. While the framework of the GEC emphasises 21CS development, its reliance on traditional assessment methods and the exclusion of technology potentially restricts learners' opportunities to develop these skills in authentic, technology-enhanced contexts. This strategy of the GEC might lead to missing a common objective emphasised by Benvenuti et al (2023), that education should transition from having a culture of knowledge to a culture of fostering competence and skills. The limitations of having a content knowledge approach alone are explained by Dewey (1983/1997) as not preparing a learner for future experience, and thus, teachers cannot solely rely on content learning to foster 21CS.

As argued by Barrot (2023) a curriculum must fully represent the competencies that the world demands of 21st-century learners to prepare learners to thrive in a technology-driven and skill-based society. However, the current GEC design overlooks how to equip young generations with the capabilities needed for an AI-integrated world. This failure to acknowledge the transformative potential of AI in shaping learning and work experiences may leave learners unprepared for a future dominated by technology (Carvalho et al., 2022).

1.4 Research Aims and Objectives

Given the current limitation of the GEC to foster 21CS without AI integration, this study aims to explore the possibilities and challenges of using a generative Socratic AI-enabled tutoring platform in learning mathematics.

1.5 Purpose of the Study

The research for this study aims to look at integrating a generative AI-enabled Socratic tutor in Grade 9 Mathematics to explore the fostering of 21CS while learning mathematics on a Socratic generative AI-enabled tutoring platform called Mindjoy. Furthermore, the research also explores learners' perceptions of the possible roles that a Socratic generative AI tutor can play in the learning process facilitated by Mindjoy.

1.6 Research Objectives

Given the current limitation of the GEC to foster 21CS without AI integration, this study aims to explore the possibilities and challenges of using a generative Socratic AI-enabled tutoring platform in learning mathematics.

To identify the potential of Mindjoy to function as a generative Socratic AI-enabled tutoring platform.

To explore the opportunities and challenges of fostering 21st-century skills through integrating Mindjoy as the generative Socratic AI tutor into Grade 9 Mathematics learning.

To understand the learners' view on the role of the generative Socratic AI tutor during the learning process facilitated on Mindjoy.

1.7 Research Questions

This study explores the following research questions:

1. What is the potential for Mindjoy to function as a Socratic generative AI tutor in a mathematics learning environment?
2. What are the opportunities and challenges of fostering 21st-century skills through integrating Mindjoy as the generative Socratic AI tutor into Grade 9 Mathematics learning?
3. How do learners perceive the role of a generative Socratic AI tutor during the learning process facilitated on Mindjoy?

1.8 Significance of the Study

This research addresses a critical gap in current educational practice, particularly within the South African context. As Barrot (2023) emphasises, education systems globally need to create learning environments that foster all competencies of 21CS, including the ability to use and understand AI tools (Chang & Kidman, 2023). By investigating the integration of AI-enabled Socratic tutoring in a Grade 9 GEC Mathematics learning environment, this study contributes to:

- Understanding how AI can support the development of 21CS in mathematics education,
- Informing potential enhancements to the GEC framework regarding technology integration,
- Providing insights into learner experiences with AI-enabled tutoring, and

Contributing to the broader discourse on AI literacy in education

1.9 Theoretical Framework

The choice of epistemology within a teaching space will influence teaching methods, and it will impact how we design learning (Bates, 2015). As Sandoval (2004) argued more than two decades ago, it is important to explain the choice of a theoretical framework, as it sets the context of the study. Exploring a generative AI tutoring system lends itself to many possibilities as learners take different learning paths, depending on their interaction with the AI platform. A well-established theoretical framework can be helpful to use to interpret all the different possibilities. (Arroyo et al., 2003). This study was informed by Social Constructivism, credited to Lev Vygotsky, and his research on the construction of knowledge through social interactions (Shah, 2019; Vygotsky, 1978). Laurillard's (2013a) Conversational Framework was positioned as the conceptual framework for this study, to provide the specific lens through which the learning interaction between the learners and the AI tutor will be explored. A further discussion of the theoretical framework is given in Chapter 2.

1.10 Chapter Summary

The transformative impact of AI in education (Kasneci et al., 2023), necessitates integrating AI literacy alongside AI applications (Ng et al., 2021). Within the South African context, the Department of Basic Education's General Education Certificate (GEC) framework aims to foster 21CS, yet its current assessment strategy reveals limitations in measuring and observing these skills in Grade 9 Mathematics. As Benvenuti et al. (2023) emphasise, education should transition from having a culture of knowledge assessment only to fostering assessing competence and skills. This study investigates the integration of a generative AI-enabled Socratic tutor (Mindjoy) to explore its potential in fostering 21CS, examine implementation challenges and opportunities, and understand learners' perceptions of the AI tutor's role. Grounded in social constructivism (Vygotsky, 1978) and Laurillard's Conversational Framework (2013a), the research aims to explore opportunities and challenges for AI-enabled mathematics education. Furthermore, the study acknowledges limitations such as rapid AI development, confined Problem-Based Learning timeframes, and varying levels of AI literacy among participants (Zheng et al., 2024).

In Chapter 2, a review of the literature will explore the theoretical underpinnings of this study, with Vygotsky's Zone of Proximal Development and Laurillard's Conversational Framework as primary frameworks. Literature on the use of Problem-Based Learning in technology, the evolution of AI in education and mathematics learning, as well as Socratic learning approaches, twenty-first-century skills, and the envisioned roles for AI in learning mathematics, are important themes that are discussed in the next chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the literature that underpins this study's exploration into AI-enabled mathematics learning and its potential for fostering 21st-century skills. The review begins by establishing the theoretical foundation through Vygotsky's Social Constructivism and the Zone of Proximal Development (Vygotsky, 1978), and Laurillard's Conversational Framework (Laurillard, 2013a), which provides the lens through which the AI-enabled learning interactions are explored. The literature review was conducted using a systematic approach based on three primary themes: (1) Generative AI, (2) Socratic Learning, and (3) Twenty-first-century skills. The primary themes are posed as Socratic Learning, 21st-century skills and AI in education, and then it is further reviewed in the context of an AI-enabled mathematics learning ecosystem. Through exploring these themes in the existing literature, the chapter aims to identify gaps in the current understanding regarding the integration of Socratic AI-enabled tutors for mathematics learning.

2.2 Literature Search Methodology

The themes discussed in Section 2.1 of this chapter were expanded through the snowball effect, and additional keywords and phrases emerged during the review process. Two academic search engines, Google Scholar and ERIC, were selected based on their coverage, free availability, and access to full-text articles.

2.3 Theoretical Framework

This study draws on Vygotsky's social constructivism theory, particularly the Zone of Proximal Development (ZPD). The literature review for this study explored ZPD applications across traditional classroom settings and digital learning spaces, including AI-enabled environments. Due to the emerging nature of AI in education, the literature review encompasses both established digital learning research and the newer domain of AI-enabled learning, as studies specifically focused on ZPD within AI contexts remain limited. Building on Chounta et al.'s (2017) computational approach to modelling the ZPD, this study explores scaffolding with an AI tutor who assumes the role of the more knowledgeable other. This research explores Grade 9 Mathematics learning through the interaction between learners' prior mathematical knowledge and

Socratic AI tutoring by analysing the potential of the AI tutor to identify and operate within a learner's ZPD.

Vygotsky's Zone of Proximal Development.

The Zone of Proximal Development (ZPD) has been generally interpreted as the difference between what a learner can do independently and what they can achieve with guidance and collaboration from a more knowledgeable other (Shabani et al., 2010; Vygotsky, 1978). For the ZPD to be effective, meaningful interaction between the learner and the more knowledgeable other is crucial as without it, productive learning cannot occur (Kolly-Shamne, 2022). Teachers traditionally fulfil the role of the more knowledgeable other within the ZPD, but research also explores how technologies can complement this collaborative function in digital learning spaces (Arroyo et al., 2003; Isaac et al., 2023; Luckin & Du Boulay, 2016). Mudi and Samanta (2024) describe this collaboration with a more knowledgeable other as scaffolding and, in their paper, they identify opportunities for using AI-powered tutors for scaffolding.

AI as the Digital Knowledgeable Other: A Modern ZPD Framework

Early research into AI-enabled learning within the ZPD was conducted by Arroyo et al. (2003) who explored the use of a computer-based tutor that used AI techniques to provide personal mathematics support for learners between 9 and 12 years old. Luckin and Du Boulay (2016) also reconceptualised the role of the collaborative partner in the ZPD by exploring how computers may be able to take on this role. Chounta et al. (2017) proposed a similar computational approach to model the ZPD of learners who learn with Intelligent Tutoring Systems (ITSs). More recent research on AI-induced guidance in the ZPD was done by Ferguson et al. (2022) and in their study they used a ZPD-based narrative-centred learning environment. Another study done by Isaac et al., (2023) showed that a learning environment with AI moves learners into their ZPD while giving learners support as a collaborative learning partner.

Mudi and Samanta (2024) explain that support from a more knowledgeable other in the context of applying Vygotsky's ZPD for social learning in a digital age can look like this:

- Modelling: Show the steps of solving a problem,
- Prompting: Providing cues,
- Questioning: Elicitation of answers through questioning, and
- Feedback: Comments or insights for improvement or corrections

This concept of scaffolding within the Zone of Proximal Development (ZPD) is closely related to the learning cycles presented in Laurillard's Conversational Framework (CF), which is used in this study as a conceptual framework.

Laurillard Conversational Framework

Laurillard (2013a) developed the Conversational Framework to use when exploring new technologies in learning. Laurillard's work has a strong reference to Vygotsky and social constructivism, and the relevance thereof shows that what it takes to learn has not changed, but rather in how we motivate and enable formal learning.

As illustrated in Figure 1, the CF occurs on two levels (conceptual and practice levels) through five communication cycles. Understanding these cycles is essential for seeing how learning happens through conversation and interaction. The five cycles work together to create a complete learning experience:

The five communication cycles between teacher and learner are:

1. Teacher communication cycle - At the conceptual level, the teacher explains concepts and ideas to help learners understand the theory behind what they're learning.
2. Peer communication cycle - Also at the conceptual level, learners talk to each other about concepts, sharing their understanding and learning from different perspectives.
3. Teacher modelling cycle - This bridges both levels as the teacher demonstrates how to apply the concepts in practice, showing learners what the theory looks like in action.
4. Peer modelling cycle - Learners work together at the practice level, showing each other different ways to solve problems and apply what they've learned.

- Learner generates and modulates cycle - This is where learners practice independently, and try things. Learner-learner generates and modulates.

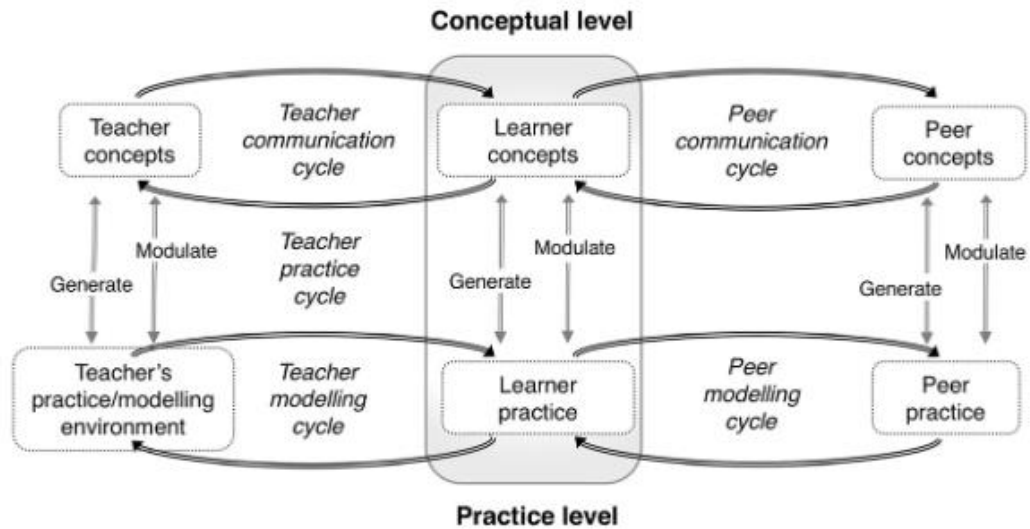


Figure 1: The Conversational Framework

Understanding Figure 2: AI Tutor and Learner Roles

Figure 2 represents how the conversational framework works when the AI tutor takes on the teaching role. The diagram shows two clear levels with specific roles for both the AI tutor and the learner:

At the conceptual level, the AI tutor starts the learning cycle through Socratic questioning, asking questions that make learners think about mathematical concepts rather than just giving answers. The learner responds to these questions, which shows their understanding and reveals where they might be confused. This creates a conversation where both the AI and the learner are actively engaged in exploring mathematical ideas.

At the practice level: The AI tutor models mathematical thinking by generating explanations and step-by-step solutions when learners need to see how concepts work in practice. The learner starts the cycle at this level by prompting, asking specific questions or requesting help with particular problems. This shows that learners take charge of their learning by asking for what they need.

How the levels connect: The connection between conceptual and practice levels happens naturally as learners move from asking "What does this concept mean?" (conceptual level) to "How do I use this to solve a problem?" (practice level). The AI tutor supports both types of learning through different approaches - questioning for conceptual understanding and modelling for practical application.

In the same way that the teacher is motivating the learner in Figure 1, the exchange of dialogue (communication) with the AI tutor motivates the learner to create prompts through Socratic questioning. Also, similar to the teacher modelling a mathematical concept by explaining something to the learner orally, the AI tutor can use its ability to generate explanations in the chat, thus also modelling a mathematical concept and enabling the learner to practice this.

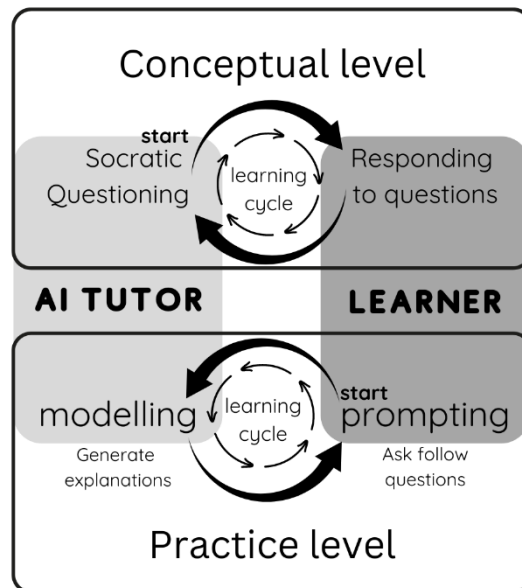


Figure 2: Conversational Framework (Adapted for AI-enabled learning)

Laurillard’s (2013a) model shares a similar approach to Mudi and Samanta (2024), who argue that support from a more knowledgeable other in the context of applying Vygotsky’s ZPD can come from an AI tutor through four modes of scaffolding: modelling, prompting, questioning and responding. The iterations of the learning cycles on both levels will be influenced by interactions between the AI tutor and the learners, influenced by the four modes of scaffolding.

For this study, social constructivism provides the theoretical foundation for understanding how learning occurs, while Laurillard's adapted CF provides the ecosystem within which the study will be explored. Another important concept for this study is the pedagogical approaches which will be used for AI-enabled mathematics learning on the Mindjoy platform. The following section reviews the implementation of Problem-Based Learning (PBL) as an approach to learning with AI. Problem-based learning (PBL) emerges as particularly significant in the context of AI-enabled learning.

2.4 Problem-Based Learning Reimagined

The Problem-based learning (PBL) approach stems from the learning theory of active construction, which underpins a learner-centred pedagogy (Miller & Krajcik, 2019; Rindengan & Wenas, 2020). PBL also involves a change from teachers being subject experts to being facilitators and learners no longer passive but active problem-solvers (O'Brien et al., 2011). There seems to be an increase in technology integration in PBL (Miller & Krajcik, 2019) and this further results in the adoption of AI tools, which calls for an alteration in the traditional approach of PBL (Zheng et al., 2024). Tang et al. (2024) explain this reimagining of PBL as learners working in teams and integrating existing knowledge through an AI-enabled platform. The AI-enabled platform or technology used in PBL can be described as a 'cognitive tool', indicating that these technologies help with collecting, processing and synthesising information to better engage with critical thinking (J. Thomas, 2000). The integration of various technology tools has been discussed in previous studies (Crawford et al., 2024), but according to Zheng et al. (2024), the impact of AI in PBL has been less studied.

2.5 A time capsule of the history of Artificial Intelligence

A question was asked in 1950 by Alan Turing (1950) in his seminal article, "Computing Machinery and Intelligence", about the ability of machines to think like humans. Turing's work focused on a test, known as the Turing Test, to determine a computer's intelligence. Five years later, in 1955, four visionary scientists, John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon, drafted a historic proposal that would forever change the landscape of computing and education. The title of the study was: The 1956 Dartmouth Summer Research Project on Artificial Intelligence, which had a core conjecture that machines could simulate any aspect of learning or intelligence, provided these processes could be described with enough precision (Mccarthy et al.,

2006). Turing and the Dartmouth Summer Research Project paved the way for a preliminary framework for artificial intelligence in education (Popenici & Kerr, 2017). The late 1960s marked AI's first meaningful entry into education through two significant innovations called Intelligent Tutoring Systems and Intelligent Learning Environments (Kulik & Fletcher, 2016; Luckin & Du Boulay, 2016). These systems pioneered one-on-one learning environments, where learners could interact with AI-based applications that adapted to their needs, though concerns about effectiveness, human interaction, and learner privacy emerged (Du Boulay, 2019; Xu et al., 2019). However, these early systems were limited by the technology available at the time. They could adapt to learner responses in pre-programmed ways, but they couldn't engage in the kind of open-ended, conversational interactions that characterise effective human tutoring. This limitation meant that whilst they showed promise, they couldn't fully replicate the dynamic, responsive nature of human-to-human learning interactions. As technology advances computers gain the ability to train themselves through data input (Muniasamy & Alasiry, 2020) and today, AI stands ready to offer adaptive learning experiences that can continuously adjust to learner needs (Almeida & Simoes, 2019). The emergence of generative AI represents a significant shift from these earlier systems. Unlike the pre-programmed responses of traditional AI tutors, generative AI can engage in genuine conversation, ask follow-up questions, and adapt its responses based on the specific context of each interaction. This suggests that current AI tutoring systems may finally be able to deliver on the promise that earlier systems couldn't fully achieve.

2.6 AI in Education Today

AI in education has gained increasing attention among researchers and educators across the world (Ng et al., 2023). It has changed everything due to the possibility of billions of learners and teachers having access to a tool that can potentially be the ultimate education technology (Mollick, 2024). Having access to a Generative AI tool like ChatGPT is disruptively changing teaching and learning as learners can now effortlessly convert a single prompt into an academic essay and teachers can offer streamlined lesson designs or deliver tailored feedback. (Hughes, 2023). Amidst all this excitement and change, many people still have a hard time trusting AI and using it (Gillath et al., 2021). Irrespective of the reason that causes this mistrust, it may reduce or prevent the integration of AI tools into education (Chakraborti et al., 2017). Thus, the importance of studying how the integration of AI works in school settings is crucial for assessing whether the use of AI aligns with

the intended purposes and outcomes of learning (Orsoni et al., 2023). AI should enhance education and human interaction rather than replace it, with systems designed to support learning while following ethical guidelines (Huang et al., 2021; Mota-Valtierra et al., 2019).

2.7 Integration of AI in Mathematics Education

The literature shows a growing recognition of AI in mathematics education and researchers have provided valuable guidance for future academic investigations in this domain (Hwang & Tu, 2021). Artificial intelligence has the potential to transform mathematics education by offering personalised learning, adaptive assessments, and interactive experiences (Opesemowo & Adekomaya, 2024), However, Huang et al. (2021). emphasise that the integration of AI in education must be approached cautiously, considering critical factors such as learner privacy protection, potential algorithmic biases, and the importance of maintaining human-centred educational practices. Through AI-powered systems, teachers can analyse learner performance data to identify areas of weakness and provide targeted support and resources (Davenport et al., 2020). This personalisation extends to real-time assessment and feedback, allowing learners to track their progress and address misconceptions quickly (Hooda et al., 2022). By assessing the interactions between learners and an AI tutor teachers can identify struggling learners for early intervention (Srinivasa et al., 2022). Integrating AI into Mathematics education can also support the adaptability of educational activities based on learners' context and learning needs (Fernandes et al., 2023)

2.8 The art of Socratic questioning

In their book, *The Art of Socratic Questioning*, Paul and Elder (2006) discuss two possible uses of Socratic questioning in teaching. The first is to guide learners in thoroughly examining their thoughts and understanding of a concept. Through careful questioning, learners are guided on what they genuinely comprehend versus areas where their knowledge is incomplete or uncertain (Chian, 2020). Another possible use of Socratic questioning mentioned by Paul and Edler (2006) is to develop critical thinking skills. The nature of a question to be Socratic is also classified in their book as either being clarifying, probing or reflective. Examples of each type of Socratic question can be seen in the following paragraphs:

- Clarifying Question: How does this relate to our discussion?

- Probing Question: How can you verify this answer?
- Reflective Question: What is another way to look at it?

These three criteria were also used in the data analysis of this study as illustrated in Table 1 (see page 17 in Section 2.10 of this chapter).

2.9 Socratic Learning in Mathematics

By implementing Socratic Learning in Mathematics, the teacher allows the learners to use their reasoning through recollecting knowledge rather than using traditional teaching of direct instruction (Wohl, 2021). Using the Socratic method in learning Mathematics challenges the learners to discover their misconceptions in their reasoning of a concept (Chian, 2020). If a misconception is not challenged, it can become resistant over time (Menz et al., 2021), which can be addressed by using Socratic learning (Chian, 2020). Maysun et al. (2023) also found that Socratic learning can be applied to foster a learning environment for Mathematics that promotes critical thinking skills. Mahoney et al. (2023) found that lessons based on Socratic dialogue are a promising intervention for teaching critical thinking, with learners constructing deeper subject knowledge through resolving cognitive conflicts in question–answer exchanges. More recently, Fakour and Imani, (2025) demonstrated that structured Socratic questioning, even when delivered by an AI tutor, enhances critical thinking by pushing learners to clarify misunderstandings and deepen their engagement with content.

2.10 AI-enabled Socratic tutoring

Socrates pioneered critical thinking through intimate, face-to-face dialogues, fostering intellectual growth through direct verbal exchange (Okpara et al., 2024). To master the art of Socratic questioning, generative AI tutors would have to mirror this pedagogical constructivist approach by encouraging learners to be active participants in the learning process (Brickhouse & Smith, 1994). In a classroom setting, this method of learning would cultivate learners' ability to question their preconceptions or misconceptions on a subject matter, fostering critical thinking skills to enable them to assess answers and solutions for themselves (Dinkins & Cangelosi, 2019). Education as we know it has forever been interrupted, or disrupted (depending on your perspective), and this is largely due to the significant transformation generative AI is bringing to modern education (Liu et al., 2024). The capabilities of AI and specifically generative AI tools in education go beyond

evaluation and assessment, they encompass the possibility of translating educational resources and creating adaptive learning spaces (Grassini, 2023). AI tools and platforms hold great potential for improving learners' outcomes and enabling teachers to be more adaptive in the learning process based on individual learners, enhancing the overall learning experience (Adiguzel et al., 2023). The remarkable effectiveness of personalised tutoring is not a recent discovery. Over four decades ago Bloom (1984) reported in his paper, *The 2 Sigma Problem*, on the powerful impact of individualised one-to-one tutoring. Bloom found that learners who received one-on-one tutoring performed two standard deviations better than those learning in conventional classroom settings. The problem was that this level of personalised attention seemed impossible to provide at scale, hence "the 2-sigma problem." The introduction of Socratic generative AI tutors presents novel opportunities to implement Bloom's findings on a scale previously considered unattainable (Walter, 2024). What makes this significant is that AI tutors can now provide the kind of individualised, responsive interaction that Bloom identified as so powerful, but without the limitations of human availability and cost (Chine et al., 2022). AI tutors can work with unlimited numbers of learners simultaneously, provide 24/7 availability, and adapt their questioning strategies based on each learner's responses (Thomas et al., 2023), all while maintaining the personalised attention that made Bloom's tutoring approach so effective. The opportunities that AI-enabled Socratic tutoring presents include:

- i. The ability to scale personalised learning beyond what was previously possible (Lin et al., 2023),
- ii. Adaptive questioning that responds to individual learner needs, and continuous availability that extends learning opportunities beyond traditional classroom time (Horvers et al., 2024).

In this sense, AI-enabled tutoring doesn't just replicate traditional one-on-one instruction but potentially enhances it through technological capabilities that human tutors cannot match, whilst still maintaining the essential dialogue and questioning that made Bloom's approach so successful. Research by Morkel (2017) on Socratic learning in online environments demonstrates how digital platforms can maintain the essential elements of Socratic dialogue while leveraging technology to enhance accessibility and scale. This aligns with the potential of generative AI tutors to deliver personalised learning experiences through structured yet adaptive interactions.

Laurillard's CF (2013) as an analytical tool, in collaboration with Paul & Elder's (2006) work on Socratic Questioning was used in this study as the conceptual framework to analyse the data collected in the chat dialogues, aiming to answer Research Question 1. The analytical tool shown in Table 1 will be used to provide a dual perspective for data analysis by exploring the following:

1. Whether using Mindjoy as an AI tool created a richer learning of mathematics through interacting with a generative Socratic AI tutor (Holmberg, 2017; Laurillard, 2013b), and
2. How effectively Mindjoy mirrored Socratic Learning by effectively applying Socratic questioning (Paul & Elder, 2006).

Table 1: Analytical Tool for exploring Mindjoy's Socratic Questioning ability

IDENTIFYING CRITERIA	DESCRIPTION	EXAMPLE
<p><u>Socratic Question Type:</u> Clarifying question</p> <p><u>Laurillard's CF:</u> Motivates learners in this step to seek evidence by posing questions.</p>	<p>Did the AI tutor ask for more information or explanation from the learner?</p>	<p><u>Prompt:</u> Calculate the area of a circle with a diameter of 9 cm.</p> <p><u>AI Response:</u> <i>What do you need to calculate the area of a circle?</i></p>
<p><u>Socratic Question Type:</u> Probing question</p> <p><u>Laurillard's CF:</u> Encourages engagement in the discourse by eliciting further information.</p>	<p>Did the AI tutor delve deeper into the current scenario or problem, probing for critical thought?</p>	<p><u>Prompt:</u> I need the radius, to calculate the area.</p> <p><u>AI Response:</u> <i>"Can you explain why you need π and the radius?"</i></p>
<p><u>Socratic Question Type:</u> Reflective question</p> <p><u>Laurillard's CF:</u> Motivates learners to think about their problems with follow-up questions.</p>	<p>AI continue with subsequent responses, prompting the learning to think more about the problem and with could be a solution.</p>	<p><u>Prompt:</u> No, I have none.</p> <p><u>AI Response:</u> <i>What do you have? If you take the given measurements, together with that is given as 3,14. Can you calculate the area now?</i></p>

2.11 Twenty-first-century Skills

The term '21st-century skills' (21CS) is subject to ambiguity, as various organisations, researchers, and policymakers may emphasise different skills as essential for success in today's digital society

(Chen, 2023). The Glossary of Education Reform (2016) broadly defines 21CS as a set of competencies necessary for diverse careers and work environments. Drawing from Chen's (2023) systematic review of 471 sources published between 2000 and 2017, 21st-century skills encompass knowledge, performances, or competencies that enable long-term achievements. In this context, 21CS can be understood as durable capabilities that individuals develop and apply to reach their goals and create positive outcomes in various aspects of life (Chen, 2023). Durable skills focus on educating learners on "how to think" rather than "what to think", fostering adaptability and critical thinking (Hughes, 2023).

The Importance of 21st Century Skills

Integrating Artificial Intelligence in the classroom has become essential for equipping learners with durable skills demanded by the digital age. The rapid pace of technological advancements necessitates that educational institutions prioritise the effective teaching of these skills to prepare learners for the evolving demands of the workforce and society (Mohamed et al., 2022). Numerous reports, including the 1997 National Academy of Sciences' *Preparing for the 21st Century: The Education Imperative*, emphasise the importance of learners developing 21CS to thrive in a competitive global economy (Kennedy & Sundberg, 2020). Recent surveys analysing 82 million job postings found that the term 21st-century learning included competencies like collaboration, communication and critical thinking (Cole et al., 2021), highlighting their significance in the modern workforce. However, many learners still enter the workplace without having adequately developed these essential skills (Minerva Project, 2023). This discrepancy between employer expectations and learners' skills underscores the need for a stronger emphasis on durable skills in education, ensuring that learners.

Twenty-first-century skills embedded in the global education curriculum.

The need for an educational approach fit for the AI era highlights the importance of integrating durable skills into the global education curriculum (Hughes, 2023). This approach is a strategic response to the evolving demands of the modern world, emphasizing the development of competencies beyond traditional academic knowledge (Mahmud & Wong, 2022) As technology advances, the global education curriculum must prepare learners for an evolving job market, as the shortage of individuals with the necessary skills will be a greater challenge than the lack of job opportunities. (Elayyan, 2021).

Educational systems worldwide must adapt their curricula to incorporate 21CS, recognising their significance for learners' success in academics, the workforce, and society (Aabla, 2017). This adaptation involves shifting teaching and learning paradigms from rote memorisation to interactive, problem-based, and technology-integrated approaches that foster critical skills (Chen, 2023). Adding AI to this equation underscores the importance of the global movement towards a more holistic approach to education, valuing the development of a broad skill set essential for living, thinking, and working collaboratively in the 21st century (Inganah et al., 2023).

The Minerva Project's white paper (2023) reinforces the importance of intentionally teaching durable skills to enable graduates to thrive in the era of technological innovation. To be intentional about integrating 21CS into the global education curriculum requires a comprehensive approach, including updating curricula, training teachers, and developing innovative teaching and assessment methods (Kennedy & Sundberg, 2020).

Fostering of 21CS within the GEC

The South African Department of Basic Education (DBE) introduced the General Education Certificate (GEC) at the Grade 9 level to recognize learners' achievements, assist in subject choices beyond Grade 9, and provide an alternative pathway to enter Technical and Vocational Education and Training (TVET) colleges after ten years of schooling (Department of Basic Education, 2021).

The GEC curriculum framework promotes five key 21st-century skills: creativity, critical thinking, communication, collaboration, and metacognition. Each skill is supported by sub-skills necessary for development (Bailik et al., 2016). Despite the DBE acknowledging the importance of 21CS in the GEC, the current toolkit lacks activities and resources utilising AI-enabled tools to foster these skills. Although AI may not have been a topic when the current GEC curriculum was designed, this can create a possible gap in preparing learners for a workforce where digital literacy has been acknowledged as a significant element for being competent (Tinmaz et al., 2022). The current GEC reveals notable limitations in its approach to developing these essential digital competencies. The current assessment methodology used by the GEC curriculum focuses narrowly on evaluating final answers rather than understanding learners' critical thinking processes and problem-solving approaches. Furthermore, learners have limited exposure to AI tools and technologies that are rapidly transforming education and the workplace. This is a concerning gap given that AI's impact on education is happening much faster and more broadly than previous technological innovations

(Mollick, 2024). The curriculum also fails to develop learners' ability to effectively use and understand AI as a learning tool, despite research indicating that learners will increasingly probably use AI as a learning companion, coauthor, or teammate in their future careers. These shortcomings in the GEC toolkit risk leaving learners underprepared for a workforce where both 21CS including AI literacy, are increasingly critical for success (Pinski et al., 2024). The design of this observation tool shows limits in enhancing 21CS within the current context of an AI-enabled learning environment, as it does not accommodate learning with AI Socratic tutors. The current Grade 9 Mathematics curriculum framework in the GEC does not foster learning with technology. With reference to the observation tool in Table 2, the three 21CS considered in teaching Mathematics are critical thinking, communication, and metacognition. The sub-skills of each 21CS are illustrated in the following table.

Table 2: The GEC Observation tool for 21CS

21st Century Skills Observation Tool									
MATHEMATICS									
Criteria of assessment	Asking questions:	Evaluating ideas:	Identifying patterns	Negotiating roles and responsibilities	Pooling resources	Engaging with roles and responsibilities	Setting goals and planning	Monitoring progress against plans	Reflecting on planned work
Sub-Skills	The learner asks appropriate questions to find out more information.	The learner identifies which information was helpful to solve the problem.	The learner uses tools (eg. mindmaps and diagrams) to help organise his/her information.	The learner negotiates and decides on the role he/she would play in the group.	The learner shares his/her own knowledge and experiences with the group to help strengthen the project.	The learner completes and submit the required tasks for the group.	The learner sets goals and makes a plan/plans during the project.	The learner monitors their progress against their plans.	The learner reflects on their project and or his/her prior knowledge.
21CS assessed	Critical Thinking			Collaboration		Metacognition			

Despite most educators acknowledging the importance of durable or 21CS, few can identify where these skills are explicitly taught in their curricula (Minerva Project, 2023). As a result, a more tailored approach is necessary to ensure the effective acquisition of new skills and competencies in a digitalised classroom (Benvenuti et al., 2023). However, the current GEC toolkit does not include AI-enabled learning tools or promote the facilitation of 21CS while learning Mathematics with an AI tutor. The observation tool primarily focuses on a content knowledge approach to foster 21CS (*GEC Training Manual*, 2023) which may be insufficient for preparing learners for future experiences outside of school (Dewey, 1997). Maintaining the current GEC approaches without incorporating AI-enabled tutors in mathematics learning exemplifies what Cukurova et al. (2023)

observe as a persistent challenge in educational technology – the slow adoption of AI-based adaptive learning platforms in schools, even when innovations like GenAI could enhance learning outcomes. Therefore, revising current curricula to integrate AI-enabled learning tools is essential for fostering 21st-century skills in our digital society. Considering these considerations, this study aims to explore the potential of using a Socratic AI-enabled tutor as a tool in the current GEC toolkit for fostering 21CS in learning Mathematics. By doing so, the study seeks to provide insights into how AI-enabled learning tools can be effectively integrated into the curriculum, addressing the gap between the skills sought by employers and those possessed by learners.

Table 3 (see page 24) shows how the work of Cole et al. (2021), and Walter (2024) was used together with the observation tool of the GEC in Table 2, to develop an adapted approach for fostering 21CS within a Socratic AI-enabled mathematics learning ecosystem. Ruiz et al. (2024) produced an AI literacy framework that was also used in the study to analyse the potential of Socratic AI-enabled tutoring in fostering 21CS. The work of Ruiz et al. (2024) was integrated into the study through three components that they represent as a framework for the implementation of AI literacy into education. The reason why the tool combines fostering 21CS with an AI literacy framework is mainly based on the work published by UNESCO as AI competency frameworks for teachers and learners (Miao & Holmes, 2023; UNESCO, 2024). These frameworks emphasise the need to use AI framework when teaching and learning with AI. Therefore, the research for this study also argued that whilst exploring 21CS within the context of an AI-enabled environment it should also be supported by a framework which guides the fostering process.

These 3 components are discussed in the following paragraph:

Understand: Gaining fundamental insights into AI's capabilities and functioning mechanisms. This knowledge forms the basis for making well-informed choices about assessing and utilizing AI systems and tools effectively.

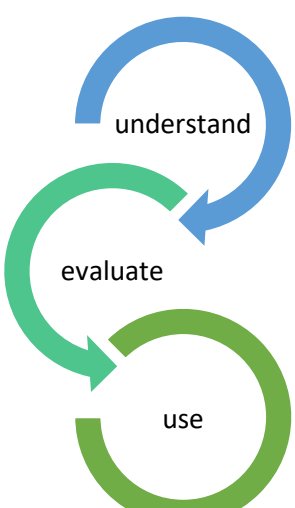
Evaluate: Prioritising human discernment and ethical considerations to critically analyse the advantages and potential drawbacks of AI implementation. This evaluation considers the impact on individuals, society at large, and environmental factors.

Use: Engaging with AI through interaction, creation, and problem-solving. This involves a progressive approach to utilizing AI across various contexts and for specific purposes, adapting

usage as needed. The tool that was used in this study to explore the fostering of 21CS is illustrated in Table 3 and it was developed by myself based on these models:

- a) A proposal by Cole et al. (2021) of durable skills needed for the 21st century.
- b) The Observation tool of the GEC (Table 2).
- c) The work of Walter (2024) on AI literacy in modern education.
- d) An AI literacy framework designed by Ruiz et al. (2024).

Table 3: Tool for exploring the fostering of 21CS within an AI-enabled learning environment

Criteria	Critical Thinking	Collaboration	Communication
<p>PROMPT ENGINEERING</p> <p>The learner crafts clear, purposeful prompts (Walter, 2024)</p>	<p>The learner asks appropriate questions to find out more information.</p> <p>The learner uses AI-generated insights to inform their problem-solving approach.</p> <p>The learner evaluates and questions AI's responses</p>	<p>The learner collaborates with the AI tutor by sharing and discussing mathematical problems.</p> <p>The learner interacts with follow-up prompts and interacts with questions asked by the AI tutor.</p>	<p>The learner sets goals and makes a plan/giving the required tasks to the AI tutor.</p> <p>The learner communicates with clarity.</p> <p>The learner articulates their understanding of the AI-provided explanations.</p>
<p>AI LITERACY FRAMEWORK</p> <p>Analysing components used (Ruiz et al., 2024)</p>			

2.12 Possible roles for generative AI in social learning

In his newly published book, Professor Ethan Mollick (2024) mentions that generative AI, like ChatGPT, acts more like a person than a computer. Mollick (2024) also highlights the possibilities of AI to act as a co-worker, teacher, expert or companion, and how we need to think about thinking with an “alien mind”, as he calls it. In this light, there is an appropriate focus for looking at some roles Generative AI can play in social learning, as set out by a study by Sharples (2023). Table 4 shows possible roles for the current generative AI system as adapted by me from the study by Sharples (2023). The original study only focused on ChatGPT; however, in this study, I have adapted it so that it can be applied to any Generative AI system like Mindjoy, within the specifics of mathematics learning.

Table 4 AI roles (adapted from Sharples, 2023)

<i>Role</i>	<i>Description</i>	<i>Example</i>
Possibility Engine	The AI tutor generates an alternative to expressing a mathematical problem.	Learners type prompts into Mindjoy and submit each prompt multiple times to examine alternative responses.
Socratic Opponent	The AI tutor acts as a respondent to elicit answers for the learning process.	Learners enter prompts into Mindjoy based on Mathematics questions they need help with.
Collaboration Coach	Acting as a partner in the learning process, the AI tutor collaborates with the learner.	Learners engage in a conversation with the AI tutor and construct knowledge through collaboration.
Co-Designer	AI tutors assist in designing a summary or visualisation of the mathematical concept.	Learners ask the AI tutor for ideas on helping to visualise abstract mathematical concepts.
Exploratorium	AI tutor provides a platform to explore and interpret mathematical problems or even personal challenges.	Learners use AI tutors to explore different things, even outside of Mathematics learning.
Storyteller	AI tutor creates stories by incorporating diverse views, abilities and experiences.	Learners ask the AI tutor to continue a story that was started by the learner and prompt the AI tutor to include the diversity of mathematical values or variables.

In the context of using a generative Socratic AI tutor for mathematics learning, one can view the AI tutor as the co-creator of knowledge, regulating the learning process and maintaining a productive learning environment. (Järvelä et al., 2018).

The impact of AI on education has been widely acknowledged, but the potential of generative AI as a co-intelligent learning partner in STEM education, which includes mathematics, has not yet been fully tapped into (Cao et al., 2023). The recent release of generative AI tools like ChatGPT caused a limited time of availability to examine the applications of the large language models on school subjects like mathematics, resulting in the scarcity of research on this topic (Jia, 2023).

2.13 Chapter Summary

The future of education hinges on how we harness Artificial Intelligence's potential in learning (Faisal et al., 2023). Through examining relevant literature, three interconnected themes emerged: twenty-first-century skills, Socratic Learning, and Generative AI. Vygotsky's social constructivism and Laurillard's Conversational Framework provide the theoretical foundation for understanding AI-enabled learning interactions, while tracing AI's evolution from Turing's foundational work reveals its growing impact on Problem-Based Learning and the transformation of Socratic questioning from traditional face-to-face dialogues to AI-enabled interactions (Tang et al., 2024; Okpara et al., 2024). Within the South African context, critical gaps exist in the General Education Certificate framework, particularly in incorporating AI-enabled tools for fostering 21st-century skills in mathematics education. By synthesising various frameworks and considering AI's potential roles in social learning (Sharples, 2023; Cole et al., 2021; Ruiz et al., 2024), this review establishes the groundwork for exploring how AI-enabled Socratic tutoring can enhance mathematics education while nurturing essential skills for our digital age.

The methodology for investigating these concepts in practice follows in the next chapter.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter outlines the methodological approach that aims to address the research questions investigating Mindjoy's potential as a Socratic AI-enabled learning platform. The methodological choices were guided by Clough and Nutbrown's (2012) emphasis on aligning methodology with research objectives, and Ratan et al.'s (2019) focus on letting research questions guide methodological decisions. Following Bloomberg and Volpe's (2022) approach, I position myself as an active participant in the research rather than producing a detached clinical report. The methodology combines Discourse Analysis (Fairclough, 1995) with Computational Grounded Theory (Nelson, 2020) to explore chat dialogues, observations, and questionnaire responses in the context of a Socratic AI-enabled mathematics learning space. This chapter presents the research paradigm, research design, population and sampling procedures, data collection methods, and data analysis techniques, and concludes with credibility, rigour, and ethical considerations.

3.2 Research Paragraph: An Interpretive Approach

This study is positioned within the interpretive paradigm, which acknowledges that multiple interpretations of a phenomenon can exist (Kivunja & Kuyini, 2017). These varied interpretations are also possibly influenced by the source of data for interpretive research, which normally represents the experiences and meanings of those who are the sources of the study (Cohen et al., 2017). As the researcher, my role as described by Denzin and Lincoln (2017), is to interpret the chats between learners and AI tutors to identify themes and patterns that capture the essential meaning of the phenomenon under study. Grix's (2004) view on interpretivism emphasises that interpretivism is based on the notion that individuals construct their understanding of the world through social interactions. In my study, the 'world' is represented by the interaction between learners and non-human, Socratic AI tutors, and this serves as the data for my interpretation. By immersing myself in the data and analysing learner-AI interactions, I aimed to construct an understanding of:

- Mindjoy's potential to function as a Socratic generative AI tutor,
- The development of 21st-century skills, and
- The possible roles of AI tutors in Mathematics learning.

This interpretive approach, grounded in the analysis of the chat dialogues, enabled the exploration of the potential of Mindjoy's Socratic ability, fostering 21st-century skills, and identifying possible roles of AI tutors in mathematics education.

3.3 Research Design

The interpretive approach contextualises the research design by acknowledging that in my study, the dialogue between the learners and the AI-enabled tutor may have many different interpretations. On the one hand, the interpretive approach will explore the content of *what* is said in the dialogues and on the other hand, discourse analysis will focus on *how* it is said. Discourse analysis is therefore used to give context and interpret how people communicate and to make meaning through multimodal text in specific social contexts and practices (Gee, 2014). Rymes (2015) also argues that this type of research design can contribute greatly to understanding classroom interactions through close examination of data in the form of dialogue. The primary data for this study were derived from dialogues between learners and the Socratic AI Tutor, thus serving as a reason for finding discourse analysis as a suitable qualitative approach for the study.

Classroom discourse analysis provides valuable insights into learner-teacher interaction and the learning process (Alsoraihi, 2019). This study extends the concept of classroom discourse analysis to a novel context: An AI-facilitated learning environment. The intention of this study was for learners to engage in Socratic dialogues with a generative AI tutor, creating a unique form of learner-centred interaction that merits careful analysis to understand its impact on learning processes and outcomes.

3.4 Population and Sampling

The study sample was drawn from the cohort of learners who were in Grade 9 in the previous year and are currently in Grade 10 at High School L. The previous year's Grade 9 cohort was chosen for this study rather than the current (2024) Grade 9 learners. This decision was made to ensure that participants had prior exposure to the mathematics assessment methods employed by the GEC.

Target population

The study sample was drawn from the cohort of learners who were in Grade 9 in the previous year and are currently in Grade 10 at High School L. The previous year's Grade 9 cohort was

chosen for this study rather than the current (2024) Grade 9 learners. This decision was made to ensure that participants had prior exposure to the mathematics assessment methods employed by the GEC.

Sampling Method

Sampling Strategy: To minimise disruption and ensure access to computers during the research, the researcher selected participants from a Grade 10 Computer Application Technology (CAT) class using purposive convenience sampling.

Sample Characteristics:

- Current Grade 10 learners who completed Grade 9 Mathematics in 2023
- Learners aged 15-16 years
- Participants from different mathematics teachers' classes (not necessarily the researcher's previous learners)

Sample Size

The original study was designed to have 29 participants, but due to learner absences during the research period, only 26 participants who were present on all three days of data collection were included in the final analysis.

School Selection

High School L was selected as it has been designated as a pilot school for the GEC project, thus making it suitable for the study. The researcher also already had a two-year academic relationship with the school due to a previous role as a Coding and Robotics and Mathematics teacher at the school.

3.5 Research Procedures

Setting

The study was conducted at a high school in the district of Eden and Central Karoo, South Africa. To ensure confidentiality and privacy, a pseudonym of High School L is used. The study took place in the Computer Class of High School L, where each of the participants had a desktop computer and access to Mindjoy. A digital classroom was set up on the Mindjoy platform, and hard copies of activities which learners had to explore were handed out.

Data Collection Timeline

The study spanned a total of five weeks, with three separate two-hour class periods dedicated to data collection, each occurring on three different days throughout this period. The three class periods were not scheduled consecutively, allowing for a gap between each data collection session to facilitate reflection and analysis. The decline of participants on day 3 was due to a lack of interest; there was no separate selection of participants during the study.

Day 1 (13 February 2024): Introduction to Mindjoy and preliminary questionnaire via Google Forms. This day was used mainly as an introduction to Mindjoy and to ensure all logins and passwords were working to minimise errors and time wasting for the following Day 2.

Day 2 (14 February 2024): Learners engaged with the Mindjoy platform and explored prompting with the AI tutor. These activities were designed to explore various Mathematical topics within the Grade 9 Mathematics curriculum.

Day 3 (18 March 2024): A problem-based activity was handed out to the learners. The problem-based activity was designed based on the GEC project requirements of assessing Mathematics skills through Project-Based Learning (PBL) during Term 3 in Grade 9.

Table 5 provides an outline of the data collection period during the three days of research.

Table 5: Data collection period

Research Period	Method of data collection	Instruments used
<i>Day 1: 13 February 2024</i>	<i>Online Questionnaires</i>	<i>Google Forms (Appendix A)</i>
<i>Day 2: 14 February 2024</i>	<i>Activity-based questions (see Appendix D: Day 2)</i>	<i>Mindjoy</i>
	<i>Online Questionnaires</i>	<i>Google Form</i>
	<i>Observations</i>	<i>WhatsApp Voice Recorder and a notebook</i>
<i>Day 3: 18 March 2024</i>	<i>Project-based activity (see Appendix D: Day 3)</i>	<i>Mindjoy</i>
	<i>Online Questionnaires</i>	<i>Type Form</i>
	<i>Observations</i>	<i>WhatsApp Voice Recorder and a notebook</i>

Role of the Researcher

As Creswell and Poth (2016) discussed, the researcher is a key instrument that collects data by studying dialogues, observing the behaviour of participants, and interviewing them. I recognise that I am not detached from the phenomenon under study (Edge and Richards, 1998). As the researcher, I aimed to remain reflexive about my position in the research process, recognising that my interpretation is one of many possible perspectives. To maintain this reflexivity, I kept a research journal documenting my thoughts, decisions, and potential biases throughout the research process.

3.6 Data Collection Methods

To ensure an effective research process, I made use of a Research Methodology Matrix (see Table 6) to establish a clear and logical relationship between the rationale for my study and the data collection methods, as suggested by Bloomberg and Volpe (2022). The choice of data collection methods was informed by the suitability to gather data that would help me answer the research questions of my study (Tracy, 2010).

Data collection

In the context of a qualitative study, data collection is facilitated through the use of various methods, which serve as a tool for interaction and exchange of information between the researcher and the participants (Canals, 2017). A strategy employed by researchers to strengthen their findings and ensure data credibility often involves the integration of more than one data source, which means more than one data instrument (Booton, 2018). Data sources and instruments of the study are illustrated in the Research Methodology Matrix in Table 6.

Primary Data Collection Methods

Learner-AI Conversation Transcripts: Learners' responses during class while interacting with the Socratic AI tutor on Mindjoy were valuable sources for data collection. I collected the data by using Mindjoy's affordance to access the chat history of each learner who was assigned to a tutor called Lorelei. Lorelei was programmed to use a series of open-ended questions, prompts for clarification, and requests for evidence or reasoning, all key elements of the Socratic method (Paul & Elder, 2006)

Classroom Observations: The observation of the learners took place on three different school days. During the observations, I recorded the engagement levels with Mindjoy and any other use of additional resources like textbooks or calculators. These recordings were captured using a notebook to write down any observations found interesting and by using my phone to send myself voice note recordings on WhatsApp.

Self-completed Questionnaires: Two online self-completed questionnaires were shared with participants: a Google Form and a TypeForm. Both had similar outcomes; the TypeForm was used as an alternative to expose learners to something other than the normal Google Form.

Table 6: The Research Methodology Matrix

<i>Research Questions</i>	<i>Data Collection Methods</i>	<i>Research Instruments</i>	<i>Data analysis tool</i>	<i>Theoretical Framework</i>
Research Question 1: What is the potential for Mindjoy to integrate Socratic learning during Mathematics teaching?	Chat History on the Mindjoy platform.	Mindjoy	Table 1 Discourse Analysis Claude ¹ NVivo	Laurillard's CF (2013a) as learning design. Paul and Elder's (2006) work on Socratic Questioning.
Research Question 2: What are the opportunities and challenges when integrating Mindjoy into the GEC curriculum for fostering 21st-century skills through generative AI Socratic tutoring in learners?	Chat History on the Mindjoy platform. Observation during classes.	Mindjoy Audio recordings were made by the researcher on their phone.	Table 3 Discourse Analysis Claude ¹ NVivo	Laurillard's (2012) six learning types. 21st-century skills (Cole et al., 2021). Laurillard's CF (2013a) as learning design.
Research Question 3: How do learners perceive the role of a Socratic AI tutor during the learning process facilitated on Mindjoy to act as a co-intelligent partner?	Chat History on the Mindjoy platform. Self-completed questionnaires	Mindjoy Google Forms and Typeform	Table 4 Discourse Analysis Claude ¹ NVivo	Social Constructivism (Adiguzel et al., 2023; Vygotsky, 1978). Sharples (2023) view on roles of AI tutors.

¹: Claude is an AI language model developed by Anthropic, designed to engage in a wide range of tasks including analysis, writing, coding, and problem-solving through natural language interaction

3.7 Data Collection Instruments

Preliminary Questionnaire

A questionnaire was sent to the participants, one as a preliminary survey comprised of questions to add context to their familiarity with generative AI learning and also specifically with Socratic generative AI tutoring on Mindjoy (see Appendix A). Google Forms were used to administer the questionnaires. Online questionnaires offer several notable advantages, including easy access to data, improved design flexibility, and practical benefits in administration and analysis. (Braun et al., 2021). High School L regularly used online forms for academic and administrative purposes, which ensured participants were familiar with platforms like Google Forms and Typeform, thus minimising potential barriers to participation and data collection.

Chat History (text transcripts)

Learners' responses during class while interacting with the Socratic AI tutor on Mindjoy are valuable sources for data collection. I collected the data by using Mindjoy's affordance to access the chat history of each learner who was assigned to a tutor called Lorelei. Lorelei was programmed (see Appendix B), to use a series of open-ended questions, prompts for clarification, and requests for evidence or reasoning, all key elements of the Socratic method (Paul & Elder, 2006). This approach focused on encouraging learners to discover answers through dialogue and guided inquiry, promoting critical thinking and self-directed learning.

One of the two activities that were used in this study, as described in section 3.4, as **Setting**, is Project-Based Learning. The full activity can be viewed under *Appendix D: Day 3*. The activity aims to help learners decide if buying a Nespresso machine is a long-term investment.

The task involves several components:

- Participants are instructed to have a chat with an AI tutor named Lorelei to discuss and calculate whether the given assumptions are correct.
- Participants are provided with a menu from a coffee shop called Plato, showing prices for various coffee drinks.

Participants are given four statements/assumptions to analyse:

- a. Saving R28,95 by making a Cortado at home instead of buying one.

- b. Saving enough money to buy a machine after making 83 cups of coffee at home instead of buying from Plato.
- c. Being able to buy a Nespresso machine within 17 days if buying a Cortado every workday.
- d. Determining if buying the Nespresso machine is indeed a long-term investment and providing reasoning.

Additional information is provided about a Nespresso Mini Essenza Pure White Coffee Machine, priced at R2,399.00, and Nespresso coffee capsules (Paris flavour) priced at R105.00 for 10 capsules. The participants of the study were expected to use the provided information, including the addendum (Plato's menu), to calculate and prove their reasoning while discussing with Lorelei. An example of a chat between a learner and Lorelei is provided in the following paragraphs, in Figure 3, to illustrate this approach. Note that in the original chat interface, the conversation reads from bottom to top, with the most recent messages at the bottom.

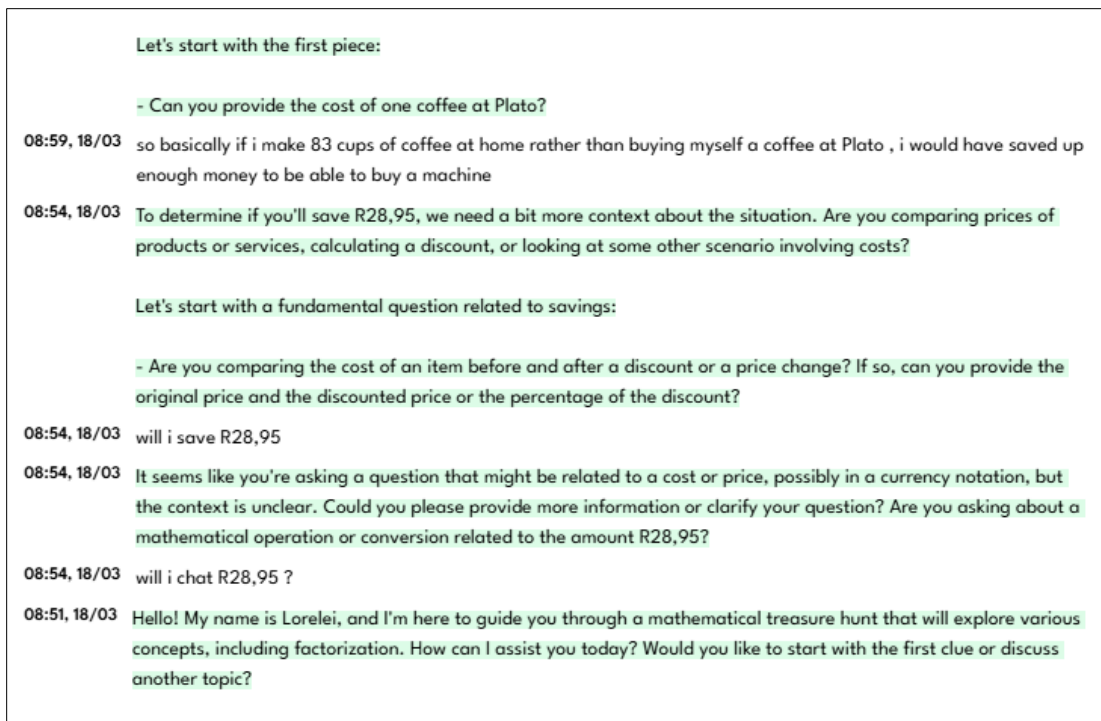


Figure 3: Screenshot of Chat Dialogue

In this example, we can see Lorelei employing Socratic questioning techniques by eliciting answers and not only giving the answers. By engaging learners in conversation and supporting them in developing their problem-solving and communication skills, Lorelei aimed to foster critical thinking, reflection, and reasoning skills. This approach allowed Lorelei to serve as a conversation partner and learning facilitator rather than simply providing answers to learners' questions.

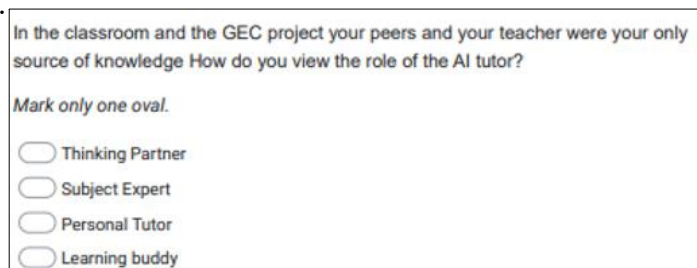
Observation

The observation of the learners took place on three different school days. Only the first day of the three days was recorded by a webcam, mainly for record-keeping as it was not used during data analysis. As the data, which was analysed mainly focused on chat dialogues, a webcam could not have provided this information by being mounded in the front of the class. The first observation was during an informal exploration of Mindjoy during which the learners familiarised themselves with the working of Mindjoy and to see if all logins worked. The second observation took place when learners interacted with Lorelei on Mindjoy by answering mathematical problems based on the GEC Project of the previous year. The last observation was done during a project-based assessment within the mathematics curriculum knowledge strand.

During the observations, I recorded the engagement levels with Mindjoy and any other use of additional resources like textbooks or calculators. These recordings were captured using a notebook to write down any observations found interesting or in line with the research. However, my main way of observing what I saw was by using my phone to send myself voice note recordings on WhatsApp. To minimize any potential distraction during the observation process, voice notes were recorded discreetly while learners were actively engaged with Lorelei and each other. The classroom environment was already dynamic with learner-AI interactions and peer discussions, which naturally masked any minimal noise from the recording process. Furthermore, to ensure privacy and reduce interference, I positioned myself at a distance from the learners when making these audio notes. This approach allowed for real-time capture of observations without disrupting the natural flow of the learning activities or compromising the authenticity of the interactions being observed.

Self-completed questionnaires with Learners

Two online self-completed questionnaires were shared with participants: a Google Form and a TypeForm. Both had similar outcomes; the TypeForm was used as an alternative to expose learners to something other than the normal Google Form. As noted by Lim et al. (2023), Google Forms for data collection has free accessibility, automatic analysing ability, and user-friendliness, which made it a visible choice for my data collection. The use of Google Forms also further allowed learners to answer anonymously and created a safe space to answer without biases or judgment from me as their interviewer (Rickwood & Coleman-Rose, 2023). Other advantages of using a self-completed questionnaire include that it can be less stressful and more convenient for the respondents and the interviewer's biases are reduced (Zimmerman, 2024). The choice of a self-completed questionnaire over that of a face-to-face interview was also influenced by the possibility of response bias (social desirability bias). This bias, as defined by Nederhof (1985) refers to a response bias in which people tend to answer questions in a way that others will view favourably or aligned with social norms. The questions might appear not to be sensitive and personal, however, the age group that was chosen as the population for this study could be quite vulnerable to social desirability bias. The potential drawbacks of self-completed questionnaires, as discussed by Phellas et al. (2011), encompass the inability to clarify questions, control over who fills out the questionnaire, and the challenges posed by low response rates. To mitigate these issues, the questionnaire was administered in a classroom setting where I was present for support, ensuring clarity and proper participant involvement. Through the first self-completed questionnaire on Google Forms (see Appendix D), learners had to answer a few questions about their view on learning with AI and possible challenges. They were also asked to identify a possible role that they see Lorelei presenting in their learning of mathematics. These roles can vary from thinking partner, subject expert, personal tutor or learning buddy (see Figure 4 inserted in the following paragraphs as it appears in the Google Form). There were 26 responses recorded.



In the classroom and the GEC project your peers and your teacher were your only source of knowledge How do you view the role of the AI tutor?

Mark only one oval.

- Thinking Partner
- Subject Expert
- Personal Tutor
- Learning buddy

Figure 4: Screenshot of the question as it appears on the Google form questionnaire

A second self-completed questionnaire was done on Typeform (see Appendix E) to gain another perspective on how learners view learning with AI in general for possible further studies. There were 10 responses recorded, as only 10 learners took part in this questionnaire, this was due to a lack of interest mostly, which will be further discussed in Chapter 5 under possible limitations of this study.

3.8 Data Analysis Techniques

Primary Analysis Technique: Inductive Thematic Analysis

The data analysis process for my study started with organising information obtained from text transcripts, observations, and self-completed questionnaires. The dialogue text transcripts from the chat history on Mindjoy were downloaded and saved as Microsoft Word documents. Observations made during classes were recorded as voice notes on WhatsApp by the researcher and transcribed using a web-based application. These transcripts were then digitally transferred to Microsoft Word documents. Both self-completed questionnaire responses (Google Form and Type Form) were exported into Microsoft Excel formats for easier analysis. Data analysis was performed using a combination of NVivo and Claude (3.5 Sonnet), an AI language model, for in-depth analysis and interpretation of the data according to conceptual frameworks, as illustrated in Table 6.

Coding Strategies

Data coding involves labelling or categorising text segments from uploaded data sources according to relevant themes or areas of interest (Kaefer et al., 2015). This process helps researchers organise, analyse, and interpret qualitative data by identifying patterns and connections within the information (Rylee & Cavanagh, 2022). The coding and sorting of data were guided by the research questions and in conjunction with the frameworks and definitions established by Paul and Elder (2006), Sharples (2023), Cole et al. (2021), and Laurillard (2013). Table 7 provides a summary of how the conceptual frameworks were used to answer the research questions by identifying themes within the data and how these were populated by assigning codes to the data.

Table 7: Coding and Sorting of Data

<i>Research Questions</i>	<i>Code</i>	<i>Conceptual frameworks</i>	<i>Theme or dimension</i>
Research Question 1: What is the potential for Mindjoy to integrate Socratic learning during Mathematics teaching?	RQ1	Laurillard's CF (2013a) as learning design. Paul and Elder's (2006) work on Socratic Questioning. <i>See Table 1 in Chapter 2.</i>	Socratic Tutor
Research Question 2: What are the opportunities and challenges when integrating Mindjoy into the GEC curriculum for fostering 21st-century skills through generative AI Socratic tutoring in learners?	RQ2	Durable skills (Cole et al., 2021) The Observation tool of the GEC (Table 2) AI literacy (Walter, 2024) AI literacy framework (Ruiz et al., 2024) <i>See Table 3 in Chapter 2.</i>	21CS Prompt engineering AI literacy
Research Question 3: How do learners perceive the role of a Socratic AI tutor during the learning process facilitated on Mindjoy to act as a co-intelligent partner?	RQ3	The six roles identified by Sharples (2023) <i>See Table 4 in Chapter 2.</i>	AI Tutor Roles

NVivo

I used NVivo, a qualitative analytic program which is a time-efficient and reliable tool for data extraction and analysis (Rylee & Cavanagh, 2022). NVivo offers several benefits, such as granting researchers control over finding important concepts, visually representing data, and enhancing the transparency of the analysis process by documenting each step (O'Neill et al., 2018). These benefits also contribute to improved methodological rigour in a study (Kaefer et al., 2015). As part of managing and sorting data, all data coding was done in NVivo after all files were uploaded to the software, which accommodates different types of files like MS Word documents, PDFs, images, audio and video (Rylee & Cavanagh, 2022). The data from the self-completed questionnaires were uploaded to NVivo as two collective Excel files with participants' responses, observation audios were uploaded as single text files, and chat dialogues were uploaded as multiple Microsoft Word files.

Discourse Analysis

An adapted version of Fairclough’s (1995) model for Critical Discourse Analysis (CDA) was employed in the data analysis as Discourse Analysis (DA) for this study. DA can be implemented as both an analytical instrument and a research design (Roos, 2019), and hence, I have used it as both in this study. DA was used to gain insights into the nature of the learner-AI tutor interactions, the types of questions and responses exchanged, the strategies employed by learners and Lorelei to negotiate meaning, and how these interactions contribute to the development of 21st-century skills (Suleman et al., 2016). This was done by using Fairclough’s model for DA, as it is set out by Janks (1997) and it has been adapted for this study as illustrated in Table 8.

Table 8: Fairclough's model for DA: adapted by myself.

<i>Dimension</i>	<i>Type of Analysis</i>	<i>Data for Analysis</i>	<i>The signifier for the research question</i>
Object of analysis	Text analysis (description)	Chat dialogue	Socratic affordances of Mindjoy – RQ1
Process of producing an object	Processing analysis (interpretation)	Typing of transcripts prompts and responses	AI literacy and 21CS – RQ2
Conditions of governance	Social analysis (explanation)	Exploring what is shaping the interaction between the learner and the AI tutor.	AI roles – RQ3

According to Janks (1997), this approach is useful because it enables the researcher to identify signifiers that might appear in the text you are analysing. I used the model to help me to analyse my data by starting with a textual analysis of the chat dialogue, then delving into the processing analysis to understand how the dialogue was produced (through what kind of learning type or Socratic question), and finally, situating the dialogue within the broader social context to determine or identify possible AI roles through social analysis.

The possible findings for my third research question (*How do learners perceive the role of a Socratic AI tutor during the learning process facilitated on Mindjoy to act as a co-intelligent partner*), were being explored by using both inductive and deductive analysis (Adu, 2019).

Inductive thematic analysis was used for the Online Questionnaire where participants had to associate with pre-determined AI roles

Deductive thematic analysis was used when a new AI role emerged from chat transcripts. For example, in the chat in the following paragraphs, the learners refer to Lorelei as “*my friend*”, after Lorelei had explained the Pythagorean Theorem. In this case, the learner's use of 'my friend' to refer to Lorelei represents a role or perception that was not previously established in Sharples's (2023) framework. This emergent category arose directly from the data, exemplifying the inductive aspect of my analysis.

By including Figure 5, I aim to show that while my coding was predominantly deductive, I remained open to new insights and categories that emerged from the learners' language and perceptions. This inductive element allowed us to capture nuances in how learners view and interact with AI tutors that might not have been anticipated by existing conceptual frameworks. However, by using Fairclough's DA (1995), one can consider the learner's mention of “*my friend*” as a possible association with a Collaboration coach or even an Exploratorium, as set out by Sharples (2023).

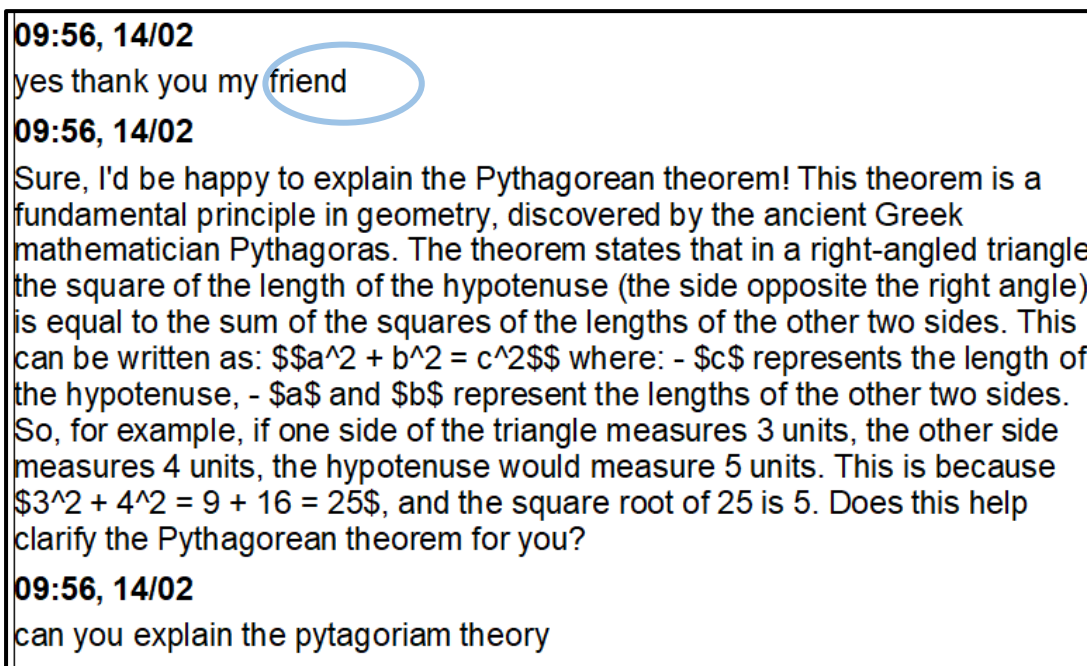


Figure 5: Screenshot of Chat Dialogue as it appears on Mindjoy

Computational Grounded Theory

I also adopted a three-step integrated approach for data analysis introduced by Nelson (2020) which uses human-driven and machine learning to recognise patterns in data. This approach, known as Computational Grounded Theory (CGT), was used as a methodological framework for analysing the data.

Three-step CGT Model:

- Unsupervised AI-enabled data analysis using Claude Sonnet 3.5
- Human-driven qualitative data analysis using DA
- Supervised AI-enabled data analysis using a trained version of Claude Sonnet 3.5.

I chose Claude as the AI assistant for data analysis within the CGT model because it can be trained as an ‘agent’ on specific frameworks without being influenced by external sources. Unlike other large language models like ChatGPT-4, which have access to the internet, Claude's knowledge base is limited to the information it is trained on. This allows for a more focused and controlled analysis of the data, as Claude's interpretations were based solely on the frameworks and criteria provided in Table 7. See Appendix N for an example of an extract from the conversation with Claude.

Implementation of the CGT model in this study:

Step 1: Unsupervised AI-enabled data analysis using Claude Sonnet 3.5:

- a) In the initial step, I uploaded the raw data (chat transcripts, observation notes, and questionnaire responses) into Claude Sonnet 3.5 without any specific instructions or frameworks. The Anthropic AI model was asked (prompted) to identify key themes, patterns and insights that emerge from the data. Claude's ability to understand context and nuance can help surface other possible themes or research possibilities.

Prompt used: “Analyze the provided data to identify recurring themes, patterns, and potential areas of interest.

- b) I used an iteration of Step 1, but I tailored it by providing Claude with sharing my three research questions, without the supervision and structure of theoretical or conceptual frameworks.

Prompt used: “Based on the following three research questions, how would you analyse the data shared with you.”

Both prompts used for this step encapsulated an unsupervised AI-driven exploratory analysis of the data for this study.

Step 2: Human-driven qualitative data analysis using DA:

- a) Following the AI's initial analysis, I conducted a Critical Discourse Analysis (DA) of the data. This involved closely reading the data collected and using inductive thematic analysis to code the data according to the conceptual models seen in Table 7. A data analysis approach recommended by Adu (2019) was used to generate a list of codes that aligned with the conceptual models and simultaneously tied to the research questions. This approach was applied in the qualitative software program, NVivo.
- b) For the second iteration of step 2, I did a focused reading of the data guided by the key points Claude identified. This allowed me to compare the computational outputs of AI and see how they align with or differ from my analysis.

Step 3: Supervised AI-enabled data analysis using a trained version of Claude Sonnet 3.5:

For the final step, I trained Claude Sonnet 3.5 on the specific conceptual frameworks and coding themes used in this study (as detailed in Table 7). The training of Claude Sonnet 3.5 needed to be done in a new chat, to ensure that it can access all the data as well as the conceptual frameworks needed for analysis. The training of Claude as an AI-enabled data analyser was done in the following way:

- a) I formulated a prompt with Claude to share what I needed:
Hi, can you please act as a qualitative data analyst and analyse the data of my study with me? I will give you all the data of my study that needs to be analyzed. I will also share with you my conceptual framework which you must engage with to understand how the data needs to be interpreted. Also, familiarise yourself with the three research questions of the study, as these are the aims of my study. I want you to only start analysing the data once I have uploaded all of the data. I will then share the prompt: START with you and then where after you may start.
- b) I uploaded the conceptual frameworks of this study (as seen in Table 7) to Claude Sonnet 3.5. The AI then analysed the data using these frameworks. The supervised analysis helped to systematically apply the conceptual model across the data, ensuring consistency and potentially identifying connections that might have been missed in the human analysis.

- c) In the final iteration of this step refinement of the data analysis took place. This was done by using Claude's outputs to test my themes and see what refinement is needed or if there were any similar analyses found between my analysis and Claude's. During this step there was a lot of engagement in a back-and-forth dialogue with Claude, probing deeper into the themes it identified and getting its perspective on how it aligns with the research questions. The results from all three steps were then compared and synthesised to produce the final analysis. This triangulated approach allowed for a comprehensive examination of the data, combining the strengths of AI-driven pattern recognition with human interpretive skills and theoretical grounding. The goal of the CTG model was to arrive at a robust, well-analysed set of identified themes which align with the research questions. I used Claude's outputs as a starting point to refine my assumptions and ideas about the findings of my study.

3.9 Credibility and Rigour

Historically, qualitative data are viewed as less trustworthy than quantitative data, Jones and Donmoyer (2021) argue that it might be because, in a qualitative study, the instrument used for data collection is largely the researchers themselves. To ensure the credibility and rigour of my qualitative study, I employed various methods to mitigate potential biases and enhance the validity of my findings. Building upon the work of Lincoln (1995), I recognised the importance of relational criteria in qualitative research, emphasising the researcher's and participants' connections. This approach acknowledges the researcher's role in shaping the inquiry and the need for transparency in the data collection and analysis processes. To achieve this transparency, I utilised triangulation by combining different data collection methods and instruments, as recommended by Bloomberg and Volpe (2022). Additionally, I utilised self-completed questionnaires as a type of interview, which can help mitigate the interviewee's bias (Gruber et al., 2008). Furthermore, I employed NVivo as a software analytical tool, documenting each step of the data analysis process to ensure transparency and accountability (O'Neill et al., 2018). Another possibility to aim for mitigating researcher bias was by adopting Nelson's (2020) CGT model, as detailed in Section 3.7.4. This model integrates unsupervised AI analysis, human-driven qualitative interpretation, and supervised AI analysis through Claude, creating an approach that may reduce potential researcher preconceptions and avoid my bias as a researcher in my preconceived ideas and beliefs.

In addition to incorporating these methods, I extracted 5 criteria from an article from Lincoln (1995) that are paramount to judging the quality of qualitative interpretive research. I have adapted the criteria in a table format (see Table 9) to describe how each criterion contributes to ensuring the quality and significance of my data for my study.

Table 9: Five criteria for judging the quality of qualitative interpretative research (Lincoln, 1995)

<i>Criteria</i>	<i>Description</i>	<i>Significance to my study</i>
<i>1. Archival Significance</i>	Contributes to the discipline's body of knowledge and understanding.	Exploring mathematics learning engagement within Mindjoy, a Socratic AI-enabled platform within the GEC of Grade 9 Mathematics.
<i>2. Relevance to Literature</i>	Specifies where the study fits within relevant literature and indicates intended contributions.	Provides a novel Literature review and discusses possible contributions as findings.
<i>3. Procedures</i>	Procedures used are appropriate or responsive to the intended contributions.	Ensured robustness and transparency by aligning the qualitative approach with research questions, promoting triangulation and reflexivity, and using qualitative software (NVivo) to enhance transparency. Implementing the CGT model as an additional data analysis method to mitigate researcher bias.
<i>4. Clarity of Procedures</i>	Procedures are specified clearly so readers can see how to conduct a similar study.	Reported detailed description of data collection, participant selection, data analysis steps, ethical considerations, researcher's role and biases, and fortnightly team meetings with supervisors.
<i>5. Limitations</i>	Limitations of the study are discussed.	Discussions are made in Chapter 4 under the section <i>Limitations and Challenges</i> .

3.10 Ethical Procedures

Publishing ethical research requires making responsible choices from the inception of the research process ensuring honesty, transparency, and accountability throughout the entire duration of the study (Wester, 2011). To ensure the thoroughness of the ethical procedure in this study the five

ethical principles as set out in an article by Wester (2011) were applied in this study. The principles and description of each principle are outlined in Table 10.

Table 10: Ethical Procedures.

<i>Principle</i>	<i>Description of principle</i>
Respect for others	The foundation of all other principles is respecting individuals participating in the study.
Autonomy	Participants should have a choice to participate in the study or not.
Protection of Vulnerable	Special precautions must be taken in the case of minors to ensure their safety during the study.
Beneficence	Protecting participants from harm during the study and the right to informed consent.
Justice	Making the benefits of the study available if the benefits to the study to the individual and society outweigh the risks to participants.

Application of Wester’s (2011) principles in the study:

Respect

I avoided seeing the participants as data points, and rather as humans and learners. Unrespectful language or unsafe responses used on the Mindjoy platform were immediately flagged. The researcher was notified via a notification, and a ‘bell’ icon next to the chat was flagged (see Appendix F). This is a very informative feature of Mindjoy that teachers can use to ensure unsafe and harmful responses are being addressed

Autonomy

During the study, no participant was forced to participate, and they also had the freedom to withdraw from the study at any time.

Protection of Vulnerable and Beneficence

I have overseen the principle of protection and beneficence as a collective approach. All participants were under the age of 18 and therefore both parental consent (see Appendix G) as well as participation consent (see Appendix H) for each learner was obtained. If a learner fails to provide the documentation it results in a no-participation agreement as mentioned in my letters to the

learners. Privacy was applied through Mindjoy's Privacy Policy, which covers not only South Africa's Protection of Personal Information Act (POPIA) but also other educational institutions' acts like FERPA and COPPA. Also, see Appendix L for a copy of the Privacy Policy as found on their website (Mindjoy)

Justice

Possible future endeavours will focus on this. Currently, most Grade 9 learners of 2023 at High School L are informed about how to use Mindjoy, and free access is available. In case any learners asked for more information about Mindjoy or ways to use it for their learning, I made a link available for them to explore the tool as well as an instructional video to guide them.

3.11 Ethical Clearance

All phases of the study process have, at best, adhered to ethical standards set out by the School of Education at UCT. Ethical approval had to be given before the primary research was conducted to guarantee that the School of Education in the Faculty of Humanities at the University of Cape Town, the organisation through which the researcher will be working, is comfortable with the way the study data will be collected (see Appendix I).

Approval Process

The School of Education granted ethical clearance for the study (see Appendix J).

Ethical approval was also sought from WCED, as this is a government school (Appendix K).

Formal approval from High School L's principal and governing body was obtained (Appendix O).

Data Protection Measures

Confidentiality and Anonymity: All participants were assigned pseudonymous codes (e.g., CB1-30) to ensure anonymity throughout data collection and analysis. High School L was used as a pseudonym for the actual school's name. No real names or identifying information were used in any research documentation or reporting.

Data Safekeeping: All digital data was stored on an internal hard drive and cloud-based system with password-protected access restricted to the researcher and supervisors. Physical documents were stored in filing cabinets. Mindjoy platform data were accessed only through secure, encrypted

connections, and all downloaded transcripts were immediately transferred to the secure cloud storage system.

Data Destruction: All research data stored on the cloud-based system will be automatically deleted at the end of 2026, following the University of Cape Town research data management policies. Any additional digital files will be permanently deleted using secure deletion protocols, and physical documents will be shredded and disposed of securely.

3.12 Chapter Summary

This qualitative interpretive study explores the potential of Mindjoy as a Socratic AI-enabled learning platform through a methodological approach aligned with the research questions and both theoretical and conceptual frameworks. The research design employs discourse analysis to examine dialogues between learners and Lorelei, supported by the computational tools NVivo and Claude for data analysis. Data collection occurred over three distinct days at High School L, involving 26 Grade 10 participants who experienced the GEC framework in their previous year. The study used multiple data sources including chat transcripts, observations, and self-completed questionnaires to ensure comprehensive data collection and triangulation. The analytical framework incorporated Laurillard's Conversational Framework and Paul & Elder's work on Socratic questioning, while also integrating Nelson's (2020) Computational Grounded Theory model for a robust analysis approach. Ethical considerations were carefully addressed through Wester's (2011) five principles, ensuring participant protection and study integrity. The research methodology was designed to provide rich insights into the interaction between learners and AI tutors, the development of 21st-century skills, and the emerging roles of AI in mathematics education. The findings from this methodological approach are presented in the next chapter.

CHAPTER 4: FINDINGS

4.1 Introduction

The previous chapters established the methodological foundation for investigating Mindjoy's potential as a Socratic AI-enabled learning platform for Grade 9 GEC Mathematics. As outlined in Table 7 of Chapter 3, the study employs multiple conceptual frameworks to analyse the data, including Laurillard's CF (Laurillard, 2013a), Socratic questioning (Paul & Elder, 2006), 21st-century skills (Cole et al., 2021) and roles for generative AI in cooperative and social learning (Sharples, 2023). This chapter presents findings derived from participant responses and researcher observations, addressing the study's three research questions about Mindjoy's potential as a Socratic generative AI tutor, its role in fostering 21st-century skills, and learners' perceptions of AI-enabled tutoring. The analysis draws on data from online self-administered questionnaires (Google Forms and TypeForm) and chat transcripts documenting interactions between learners and the Socratic Generative AI tutor, Lorelei. Through qualitative deductive thematic analysis, these data sources were aligned with the preconceived analytical frameworks to generate meaningful insights about AI-enabled mathematics learning. The chapter's structure follows the three research questions, exploring findings from both research days. Each section of the chapter integrates the relevant conceptual frameworks as discussed in section 3.7.1, Table 7. In this chapter, I apply these frameworks, aiming to understand how learners interact with a Socratic AI tutor in their mathematics learning space.

4.2 Socratic Ability of Mindjoy

Research Question 1:

What is the potential for Mindjoy to function as a Socratic generative AI tutor in a mathematics learning environment?

To assess Mindjoy's potential as a Socratic generative AI tutor, the study analysed chat transcripts using two key conceptual frameworks: Paul and Elder's (2006) work of Socratic questioning and Laurillard's Conversational Framework (2013a). The analysis focused specifically on Lorelei's responses to learner prompts across 36 chats, 26 from Day 2, and 10 from Day 3. These interactions were systematically coded using NVIVO and analysed for three types of Socratic questioning (clarifying, probing, and reflective questions) as well as specific elements of Laurillard's framework.

The research question aimed to examine Mindjoy's ability to act as a Socratic tutor, with a focus on analysing Lorelei's responses to the learners' prompts. Although the learners' prompts were necessary for contextualising the questioning, the main analysis centred on Lorelei's responses to explore whether it employed Socratic questioning techniques for mathematics learning.

The dialogues between the learners and the Socratic AI-enabled tutor, Lorelei, were analysed to explore Mindjoy's potential to provide a Socratic AI-enabled platform for mathematics learning within the GEC framework. As mentioned in Chapter 3, the data analysis involved the coding of three types of questions as adapted by the researcher from the work of Paul and Elder (2006) and this was discussed in detail in Chapter 2, Table 4. In total, 36 chats were analysed: 26 from Day 2, and 10 from Day 3. While the data shows this clear decrease in participation on Day 3, the reasons for this decline were not formally investigated in this study. Based on researcher observations during data collection, one possible explanation might be that learners were less motivated to participate as the activities did not count toward any term marks. However, this remains an observational insight only and was not verified through systematic data collection. An outline of the study's data collection can be seen in Table 5 of Chapter 3.

The chats from Day 2 consisted of dialogues derived from the interaction between Lorelei and learners' prompting on structured mathematics activities (see Appendix D, Day 2). The other 10 chats were collected on Day 3, and these 10 chats represented dialogues on a problem-based learning mathematics activity (see Appendix D, Day 3). Each of the 36 chats was read through by the researcher and the questions asked by Lorelei were coded with the criteria as shown in Table 2, Chapter 2. The study adapted and applied the work of Paul and Elder (2006) and Laurillard (2013a) to explore the use of Socratic questioning in chat-based interactions. The categories that were used for analysis, include the following criteria: (Also see Table 1, Chapter 1)

1. Questions asked in the chats by Lorelei were coded as:
 - a) Clarifying questions – did Lorelei ask for more information or explanation from the learner?
 - b) Probing questions – did Lorelei delve deeper into the current scenario or problem to motivate the learner to ask more questions?

- c) Reflective questions – did Lorelei encourage the learner to think about their thinking?
2. To further explore Mindjoy's effectiveness in eliciting information, we employed three components of Laurillard's Conversational Framework (2012):
- a) Did Mindjoy enable learners to model their understanding of a mathematical concept through the use of Socratic questions?
 - b) Were learners motivated to generate prompts, through Socratic questioning?
 - c) Was there any probing coming from Lorelei, to encourage follow-up prompts on the same problem currently explored?

The criteria mentioned in the preceding paragraph, which were derived from the two conceptual frameworks of Paul and Elder (2006) and Laurillard (2013a) were used to identify Socratic elements (see Table 1, Chapter 1) in the dialogues. These elements were used to explore Lorelei's ability to act as a Socratic tutor. Table 11 in the following paragraphs summarises the coding and sorting of the data collected as dialogues from the 36 chats. These chats were analysed according to Table 6 of Chapter 3 and using the CGT model described in Chapter 3.

Table 11: Representation of Chat dialogues and Socratic Elements on Days 2 and 3:

TOTALS:	Day 2	Day 3
Total Chats = Total learners present on the day	26	10
Total Dialogues	480	180
Chats with notable Socratic Presence	2	8
SOCRATIC ELEMENTS IN DIALOGUE	Day 2	Day 3
Probing Questions	16	37
Encouraging Critical Thinking	9	27
Guiding Discovery	6	22
Adapting to Learners' Responses	11	33
Challenging Assumptions	4	17
Seeking Clarification	13	26
Exploring Implications	2	12
TOTAL SOCRATIC ELEMENTS PER DAY	61	174

To illustrate the findings based on the process of identification of Socratic questioning explained in the preceding paragraph, parts of the dialogue between Mindjoy's AI-enabled tutor and a learner

are provided below. It is important to mention that the dialogue excerpts were taken on Day 2 and Day 3 of the research. The importance of mentioning this is on Day 2 a structured mathematics activity was handed out to learners to answer, whilst on Day 3 a problem-based learning activity was used to engage with Lorelei.

By analysing these interactions, we can better understand how Mindjoy performs as a Socratic tutor when aligning it with the conceptual models of Paul and Elder (2006) and Laurillard (2012). Day 2 of the research took place in February, and Day 3 took place in March. From these chats, dialogues between a learner and Lorelei were extracted from Mindjoy, to show the interaction patterns presenting themselves from the chats.

Day 2 – Procedural Mathematical Activity:

The dialogue in the following paragraphs shows an interaction between a learner and Lorelei. Although the conversation is found to be jumping between topics, this is one continuous chat. Also, the syntaxes of Lorelei’s presentation of mathematical formulae and calculations are not seen in this format by the learner, this is because as the researcher I am a third party in accessing the chats and therefore the display will show differently.

For example, the simple interest formula is displayed in the chat in the following paragraph:

$I = P \cdot r \cdot t$, but it is seen by the learner as:

$I = P \times r \times t$

Learners were given a practice activity (See Appendix D: Day 2 activity) to start a chat with Lorelei and then they could ask Lorelei questions on any other mathematical problem they felt they needed more support with. The focus of this activity was to encourage engagement with Lorelei and also allow learners to explore Socratic AI-enabled tutoring in their own learning space.

A conversation between a learner and Lorelei based on their exploration of mathematical topics can be seen in the following paragraph. Although Figure 5 shows the original layout of conversations on the Mindjoy platform, the chat transcripts in this chapter are presented sequentially from top to bottom to facilitate clearer analysis and reading.

Prompt^{Learner} *have a conversation on VAT*

Response^{AI} Sure, I'd be happy to help explain VAT or Value Added Tax. VAT is a type of indirect tax that is imposed on the value added to goods and services at each stage of production but is ultimately paid by the end consumer. This tax is used in many countries around the world as a major source of revenue.

Can you tell me what you understand about VAT so far?

And do you have any specific questions about it?

Prompt^{Learner} *what is VAT*

Response^{AI} VAT, or Value Added Tax, is a type of tax that is added to the price of goods or services at each stage of production, distribution, or sale to the end consumer. If you think of a product being made, such as a piece of furniture, VAT would be added at each step of the process - when the raw materials are bought, when the furniture is produced, when it's sold to a retailer, and finally when it's sold to the customer. However, businesses involved in the process can usually reclaim the VAT they've paid. It's ultimately the final consumer who is not able to reclaim the VAT and so bears the final cost of the tax. This system ensures that the tax is levied on the amount by which the value of the good has been increased at each business stage. Do you have any specific questions about how VAT works?

Prompt^{Learner} *can you explain the pythagoriam theory*

Response^{AI} Sure, I'd be happy to explain the Pythagorean theorem! This theorem is a fundamental principle in geometry, discovered by the ancient Greek mathematician Pythagoras. The theorem states that in a right-angled triangle, the square of the length of the hypotenuse (the side opposite the right angle) is equal to the sum of the squares of the lengths of the other two sides. This can be written as: $3^2 + 4^2 = 5^2$ where: c represents the length of the hypotenuse, a and b represent the lengths of the other two sides. So, for example, if one side of the triangle measures 3 units, the other side measures 4 units, the hypotenuse would measure 5 units. This is because $3^2 + 4^2 = 9 + 16 = 25$ and the square root of 25 is 5.

Does this help clarify the Pythagorean theorem for you?

Prompt^{Learner} *yes thank you my friend*

Response^{AI} You're welcome! I'm glad I could help. If you have any other questions, feel free to ask. I'm here to assist you.

Prompt^{Learner} *what is a compound and simple interest of yours*

Response^{AI} As an AI, I don't have personal interests or finances. However, I can explain what simple and compound interest are in financial terms. 1. Simple Interest: This is a quick method to calculate the interest charge on a loan. It's determined by multiplying the daily interest rate by the principal by the number of days that elapse between payments. The formula for simple interest is

$$\mathbf{I = P \times r \times t}$$

where: - I is the interest, - P is the principal amount (initial loan), - r is the annual interest rate in decimal form, - t is the time the money is borrowed for in years. 2. Compound Interest: This is the concept of adding accumulated interest back to the principal, so that interest is earned on interest from that moment on. The act of declaring interest to be principal is called compounding. The formula for compound interest is: $A = P(1 + \frac{r}{n})^{nt}$ where: - A is the amount of money accumulated after n years, including interest, - P is the principal amount (the initial amount of money), - r is the annual interest rate in decimal form, - n is the number of times that interest is compounded per year, - t is the time the money is invested for in years. These two concepts are fundamental in finance. Simple interest is generally used for short-term loans or investments, whereas compound interest is used for long-term loans or investments and can result in much higher interest over time due to the compounding effect.

Prompt^{Learner} *shrek dialouge*

Prompt^{AI} Sure, here's a snippet of dialogue from the iconic movie, Shrek: Shrek: For your information, there's a lot more to ogres than people think. Donkey: Example? Shrek: Example... Uh... Ogres are like onions! Donkey: They stink? Shrek: Yes... No! Donkey: Oh, they make you cry? Shrek: No!

How the learner starts the dialogue shown in the preceding paragraph and Lorelei's response which follows opens a few points for discussion. The learner is using "have a conversation" as a prompt for explaining VAT, this use of words might be a bit odd for mathematics learning. Further, Lorelei's response to this prompt is asking follow-up questions like:

Can you tell me what you understand about VAT so far?

And do you have any specific questions about it?

Table 12 provides a summary of the other prompts in the rest of the chat which resulted in the following responses from Lorelei.

Table 12: Summary of prompts and responses

PROMPT by learner	RESPONSE in the question format by Lorelei
<i>what is VAT?</i>	[Explanation of VAT] followed by: Do you have any specific questions about how VAT works?
<i>can you explain the pythagoriam theory</i>	[Explanation of Pathogoras] followed by: Does this help clarify the Pythagorean theorem for you?
<i>what is a compound and simple intrest of yours</i>	[Explanation of Pathogoras] followed by: NO QUESTION
<i>shrek dialouge</i>	An example of the dialogue in the movie Shrek

A pattern found across most of the chats during Day 2 was that Lorelei showed a lack of using Socratic questioning to guide the learner back to mathematical concepts or guiding the learner back to the original reference of questioning once the learner has decided to go into an irrelevant topic. For example, in the preceding paragraph extract, the learner gave a vague prompt that only stated “*shrek dialogue*”, In this exchange, when the learner abruptly switched to discussing Shrek dialogue, Lorelei neither redirected the conversation back to the mathematical topic of compound and simple interest nor demonstrated an ability to recognize and avoid non-mathematical content. This suggests a limitation in Lorelei's ability to maintain focus on mathematical learning objectives. A strength of Lorelei is however illustrated in this chat with its ability to use text prediction successfully in the misspelling of *pythagoriam theory*. Without the necessary correct context, the AI illustrated the ability to still explain the correct concept of the Pythagoras theorem. In the dialogue shown in the preceding paragraph, Lorelei's formulation of questioning was observed to be less Socratic and more conversational. When analysing the type of questions asked by Lorelei through the lens of Paul and Elder's (2006) work, the question mark which concludes a response from Lorelei does not necessarily imply that Socratic Questioning was used.

When the text of all the dialogues of Day 2 was analysed through Discourse Analysis (DA) and codes were assigned within NVivo, based on the criteria of Socratic questioning (see Table 1 in Chapter 1), it showed a low frequency of Socratic questioning.

Through the lens of the adapted Laurillard's CF (see Figure 2, Chapter 2) the following cycles or lack thereof were identified in the chats of Day 2:

- Lorelei motivated the learners to tell (show) what they understand about VAT so far.
- Additionally, Lorelei encouraged the learner to engage with specific questions on VAT and how it works.
- Follow-up prompts proved to be lacking in this chat and across other chats on Day 2 as well.

Day 3 – Problem-Based Learning Activity

Two excerpts from two different chats were taken during Day 3 which involve the discussions in the context of a problem-based mathematics activity. These activities differed from Day 2 in the way that they involved a real-life scenario which required mathematical calculations.

Learners were given a problem-based scenario (See Appendix D: Day 3 activity) and asked to engage with Lorelei. The focus of this activity was to encourage collaboration with Lorelei within a similar learning space to that which the GEC project assessment expects of grade 9 learners.

Two dialogues (a and b) of two different learners based on their collaboration with Lorelei on the problem-based activity on Day 3 can be seen in the following paragraph:

Dialogue a:

Response^{AI} Welcome to the treasure hunt! I'm Lorelei, your AI guide on this adventure through the world of mathematics. What would you like help with today?

Prompt^{Learner} *Will I save R28,95 if I decide to make a Cortado and buy a Nespresso Mini Essenza Pure White Coffee Machine to make it at home?*

Response^{AI} To figure out if you'll save R28,95 by making a Cortado at home with a Nespresso Mini Essenza Pure White Coffee Machine, we need to consider a few factors:

1. ****Cost of the Nespresso Machine****: How much does the Nespresso Mini Essenza Pure White Coffee Machine cost?

2. **Cost of Nespresso Capsules**: How much does each Nespresso capsule (or your choice of coffee for a Cortado) cost?
3. **Number of Coffees**: How many Cortados do you plan to make at home? This will help us calculate the total cost of coffee capsules.
4. **Cost of Additional Ingredients**: If a Cortado requires any additional ingredients (like milk), what is the cost of these ingredients per Cortado?
5. **Current Cost of Buying a Cortado**: How much do you currently spend on buying a Cortado?

Once we have this information, we can calculate the total cost of making a Cortado at home and compare it to the cost of buying it to see if you save R28,95.

Let's start with the first question: **How much does the Nespresso Mini Essenza Pure White Coffee Machine cost?** Clarifying

Prompt^{Learner}

Cost of the Nespresso Machine: R2 399,00

Response^{AI}

Thank you for providing the cost of the Nespresso Machine, which is \(R2,399.00\) . To proceed with our calculation to find out if you will save \(R28,95\) by making a Cortado at home, we still need a few more details:

1. **Cost per Capsule** ($\text{\(C_{capsule}\)}$): How much does each Nespresso capsule cost?
2. **Additional Ingredients Cost** ($\text{\(C_{ingredients}\)}$): If making a Cortado requires additional ingredients like milk, what is the cost of these ingredients per Cortado?
3. **Cost of a Cortado at a Café** ($\text{\(C_{cafe}\)}$): How much does a Cortado cost when you buy it at a café?
4. **Number of Cortados** (\(N\)):

How many Cortados do you plan to make at home? Clarifying

This is important to determine how the initial investment spreads out over time.

Could you provide the missing information so we can continue with our calculation? Probing

Dialogue b:

Response^{AI}

Hello, I'm Lorelei, your AI tutor. What would you like help with today?

Prompt^{Learner}

I will save R28,95 if i decide to make an cortado at home rather that buying on

Response^{AI}

That's great to hear that you're considering making a cortado at home to save money! To understand your savings better, let's delve a bit deeper. If you save R28,95 by making a cortado at home instead of buying one, it shows the cost difference between the two options.

Would you like to explore **how to calculate the annual savings if you make this choice every day, or are you interested in understanding how the cost of making a cortado at home compares to the purchase price at a café?** ^{Clarifying}

Prompt^{Learner} *is it true that i will save R28,95 if i decide to make a Cortado at home rather than buying one*

Response^{AI} To verify if you will save R28,95 by making a cortado at home rather than buying one, you need to consider a few factors:

1. ****Cost of Buying a Cortado:**** This is the price you would pay for a cortado at your favorite café.
2. ****Cost of Making a Cortado at Home:**** This includes the cost of all the ingredients (coffee, milk, etc.) and any other overhead costs (electricity, water, etc.) involved in making a cortado at home. To determine if the statement is true, you would subtract the cost of making a cortado at home from the cost of buying one. If the difference is indeed R28,95, then you are saving that amount by making the cortado at home.

Have you calculated the individual costs involved in both scenarios? ^{Probing}

Prompt^{Learner} *1-R30*

Response^{AI} To determine if you save R28,95 by making a cortado at home, we'll compare the costs: 1. ****Cost of Buying a Cortado:**** R30

2. ****Cost of Making a Cortado at Home:**** This is not explicitly given, but we can infer it from the context. Given that you save R28,95 by making the cortado at home, we subtract the savings from the cost of buying one to find the cost of making it at home. So, if the cost of buying a cortado is R30, and you save R28,95 by making it at home, the equation to find the cost of making it at home would be: $\text{Cost of Making a Cortado at Home} = \text{Cost of Buying a Cortado} - \text{Savings}$

Substituting the given values: $\text{Cost of Making a Cortado at Home} = R30 - R28,95$

Can you calculate this?

Prompt^{Learner} *R28.5*

Response^{AI} Correct, the result of $30 - 1.05$ is R28.95. So, if the cost of buying a cortado is R30, and making one at home costs you R1.05, then your savings would indeed be R28.95. You've successfully answered your own question with the calculation!

Is there anything else you'd like to explore or another question you have in mind?

Prompt^{Learner} *SO BASICALLY IF I MAKE 83 CUPS OF COFFEE AT HOME RATHER THAN BUYING MYSELF A COFFEE AT PLATO, I WOULD HAVE ENOUGH MONEY TO BE ABLE TO BUY A MACHINE*

Response^{AI} To understand if making 83 cups of coffee at home rather than buying them would save you enough money to buy a coffee machine, we need to calculate the total savings from making those 83 cups at home. Given that the savings from making one cup of coffee at home is R28.95, you can find the total savings for 83 cups by multiplying the savings per cup by the number of cups: $\text{Total Savings} = \text{Savings per Cup} \times \text{Number of Cups}$ Substitute the given values into the equation: $\text{Total Savings} = R28.95 \times 83$
Can you calculate the total savings?

Prompt^{Learner} *SO BASICALLY IF I MAKE 83 CUPS OF COFFEE AT HOME RATHER THAN BUYING MYSELF A COFFEE AT PLATO, I WOULD HAVE ENOUGH MONEY TO BE ABLE TO BUY A MACHINE*

Response^{AI} To find the total savings from making 83 cups of coffee at home, you would calculate: $\text{Total Savings} = R28.95 \times 83$ Let's do the multiplication: $\text{Total Savings} = R2402.85$ So, if making 83 cups of coffee at home saves you R2402.85, and this amount matches or exceeds the cost of a coffee machine, then yes, you would have enough money to buy the machine.
Does this help you with your calculation?

Prompt^{Learner} *R2402,85*

Response^{AI} Yes, you've got it right! With a total savings of R2402.85 from making 83 cups of coffee at home instead of buying them at a cafe, you would indeed have enough money to buy a coffee machine, assuming the machine costs R2402.85 or less. This illustrates how small savings can add up over time to afford larger purchases.

In the dialogues of both examples a and b, the occurrence of questions which are posed as Socratic questioning according to the analysis criteria of this study is apparent through Lorelei's use of clarifying and probing questions but lacks reflective questions (see **bold** clarifying/probing/reflective text in chat). The questions asked facilitated learners' acquisition of information necessary for subsequent calculations. The learners in both examples (a and b) as well as across all the other chats, show prompting skills that lack any form of proper prompting. Learners either answer a calculation or ask a question as it is given on the assessment handout (see Addendum D, Day 3). Learners do not ask follow-up questions if encouraged to do so by Lorelei, Furthermore, learner

prompting shows repetition (see dialogue b) of a question rather than an adaptation of the question that maybe was not fully answered by Lorelei according to the learner. Lorelei exhibits a mixture of Socratic responses and purely conversational comments to the learner's prompts.

The first two prompts of dialogues a and b are shown with the response from Lorelei in the following paragraph.

PROMPT by learner (a)	RESPONSE in the question format by Lorelei
<i>Will i save R28,95 if I decide to make a Cortado and buy a Nepresso Mini Essenza Pure White Coffee Machine to make it at home?</i>	How much does the Nespresso Mini Essenza Pure White Coffee Machine cost?
<i>Cost of the Nepresso Machine: R2 399,00</i>	Thank you for providing the cost of the Nespresso Machine, which is \(R2,399.00\) . To proceed with our calculation to find out if you will save \(R28,95\) by making a Cortado at home, we still need a few more details: [Follow up with questions]
PROMPT by learner (b)	RESPONSE in the question format by Lorelei
<i>I will save R28,95 if i decide to make an cortado at home rather that buying on</i>	Would you like to explore how to calculate the annual savings if you make this choice every day, or are you interested in understanding how the cost of making a cortado at home compares to the purchase price at a café?
<i>is it true that i will save R28,95 if i decide to make a Cortado at home rather than buying one</i>	To verify if you will save R28,95 by making a cortado at home rather than buying one, you need to consider a few factors: [Follow up with questions]

When compared, the minor difference between the two prompts of learners a and b resulted in major differences in the response from Lorelei. From this comparison, one can consider the effects of prompts on Lorelei's response in Mindjoy. A difference was observed in Lorelei's response based on the amount of detail given in a specific prompt. To illustrate these two other examples also taken from Day 3 are given in the following paragraph. We referred to these as Examples A and B.

EXAMPLE A	EXAMPLE B
<p>Prompt^{Learner} <i>is it true that i will save R28,95 if i decide to make a Cortado at home rather than buying one</i></p> <p>Response^{AI} To determine if you'll truly save R28,95 by making a cortado at home instead of buying one, let's start by comparing the costs involved in both scenarios.</p> <ol style="list-style-type: none"> Buying a Cortado: This involves the single transaction cost of purchasing the cortado at a café or coffee shop. Making a Cortado at Home: This includes the cost of coffee beans, milk (or your preferred alternative), and any other ingredients or resources (like electricity and water) you use in the process. <p>Question: Have you calculated the total cost of making a cortado at home, including all the ingredients and resources used?</p>	<p>Prompt^{Learner} <i>I will save R28,95 if I decide to make a cortado at home rather than buying it. A cortado is R30.</i></p> <p>Response^{AI} If you save R28.95 by making a cortado at home instead of buying it for R30, we can think about how the cost of making it at home compares to buying it. Let's start by asking: What is the cost of making a cortado at home if buying it costs R30 and you save R28.95 by making it yourself?</p>

In Example C, the learner omitted the price of the cortado in their first prompt, whilst in Example D, the learner added the price to be R30. Example C was found to complicate the scenario more by asking all these questions on comparing costs, which are not essentially needed if one can just do a simple subtraction of R28,95 from R30,00.

The chats from Day 3 did not show as much unrelated mathematics activity as during Day 2. Socratic questioning or general questioning did not steer away as much from the mathematics-related content of the activity handed out to learners on Day 3, compared to Day 2.

In the dialogues given in the preceding paragraphs, Lorelei's formulation of questioning was indicated to be more Socratic than only the conversational questions seen in Day 2. The methods that were used to analyse the text of all of the dialogues of Day 2 were also applied to Day 3. Discourse Analysis (DA) and codes were assigned within NVivo, based on the criteria of Socratic questioning (see Table 1 in Chapter 2). The analysis of Day 3's chat transcripts revealed a notably higher frequency of Socratic questioning compared to Day 2. Of the 10 chats analysed, 7 demonstrated clear Socratic characteristics while only 3 remained conversational. During these problem-based learning activities, Lorelei's responses demonstrated stronger Socratic characteristics rather than merely conversational exchanges. This marked shift from Day 2's pattern indicates that problem-based learning contexts naturally facilitate more Socratic dialogue, with the majority of interactions moving beyond simple question-answer exchanges to sustained inquiry-based learning.

Problem-Based Learning Activity extraction from Day 3:

To illustrate the findings from problem-based learning activities, Figure 6 presents the dialogue progression from chat transcript CB4-PBA, which demonstrates how sustained mathematical investigation unfolds within an AI-enabled learning environment. This dialogue represents a complete learning cycle where the learner collaborates with Lorelei to solve a real-world financial problem involving coffee consumption costs and investment decision-making. The transcript shows how problem-based scenarios create extended opportunities for dialogue exchange.

The chat transcript shows the following dialogue:

- 09:42, 18/03: (844.75 * 3) + (28.95 * 2)
- 09:39, 18/03: It seems there might have been a misunderstanding in the calculation. Let's break it down step by step to ensure accuracy. First, we calculate the total weekly savings by not buying a Cortado each... more
- 09:39, 18/03: the weekly savings would be R1534.35
- 09:36, 18/03: To verify if buying a Cortado every day of a workweek allows you to afford a Nespresso machine within 17 days, let's first establish the cost of buying a Cortado each day and then compare it to the... more
- 09:36, 18/03: If I buy a cortado everyday of a work week I will be able to buy myself a nespresso machine within 17 days
- 09:35, 18/03: That's correct! By making 83 cups of coffee at home instead of buying them at a café, you would save R2402.85. This amount could indeed be enough to purchase a coffee machine, depending on the model... more
- 09:35, 18/03: 28.95*83 = R2402.85
- 09:33, 18/03: To find out if making 83 cups of coffee at home, instead of buying them, would save enough money to buy a coffee machine, we first need to know how much money you save per cup when you make coffee at home. According to our previous calculation, you save R28.95 per Cortado made at home compared to buying one. Now, let's calculate the total savings for making 83 cups of coffee at home:

$$\{ \text{Total Savings} \} = \{ \text{Savings per Cup} \} \times \{ \text{Number of Cups} \}$$

$$\{ \text{Total Savings} \} = R28.95 \times 83$$
 Can you calculate the total savings?
- 09:33, 18/03: So basically if I make 83 cups of coffee at home rather than by myself at Plato I would have saved up enough money to be able to buy a machine
- 09:32, 18/03: Excellent! You've calculated that the cost of making a Cortado at home is R105. With the cost of buying a Cortado at R30, and assuming you save R28.95 by making it at home, your calculation confirms... more
- 09:32, 18/03: the cost of making a cortado is R105
- 09:30, 18/03: If we don't have the exact cost of making a Cortado at home, we can still work through the logic with the information we have. You mentioned a savings of R28.95 when making a Cortado at home compared to buying one for R30. Let's assume the statement about saving R28.95 is true. To find out the cost of making a Cortado at home, we subtract the savings from the cost of buying one:

$$\{ \text{Cost of Making a Cortado at Home} \} = \{ \text{Cost of Buying a Cortado} \} - \{ \text{Savings} \}$$
 Given the cost of buying a Cortado is R30 and the savings are R28.95, can you calculate the cost of making a Cortado at home using this formula?
- 09:30, 18/03: 2) no
- 09:28, 18/03: Great, you've provided the cost of buying a Cortado, which is R30. Now, to complete our calculation and see if you'll save R28.95 by making a Cortado at home rather than buying one, we need the cost of making it at home. Do you have the cost of making a Cortado at home?
- 09:28, 18/03: 1) R30
- 09:28, 18/03: To determine if this statement is true, we need to know the cost of making a Cortado at home and the cost of buying one. Let's break it down:

$$\{ \text{Cost of Making a Cortado} \} = \{ \text{Cost of Buying a Cortado} \} - \{ \text{Savings} \}$$
 Do you know how much... more
- 09:28, 18/03: Is it true that I will save R28.95 if I decide to make an Cortado at home rather than buying on
- 09:26, 18/03: Hello, I'm Lorelei, your AI tutor for today's session on factorization and its applications! What would you like help with first?

Conversation Point	Learner Action	Lorelei Response
a	"Is it true that i will save R28,95..."	Breaks down problem into components; asks clarifying questions
b	Provides cost information (R30); admits limitation ("no")	Guides systematic information gathering; adapts when data missing
c	Calculates R30-R28.95=R1.05	Validates reasoning; connects to real-world application
d	Introduces 83 cups scenario; explores 17-day timeframe	Introduces formula; guides complex calculations

Figure 6: Chat transcript for Chat CB4-PBA with reference guide (Mindjoy,2023)

4.3 Fostering 21st-century skills in an AI-enabled learning space

Research question 2:

The results from the collected data of the chat transcripts addressed the second research question: *What are the opportunities and challenges of fostering 21st-century skills through integrating Mindjoy as the generative Socratic AI tutor into Grade 9 Mathematics learning?*

To address research question 2 chats from Day 2 and Day 3 were analysed through the lens of various models discussed in Chapter 2. These models are illustrated in Table 3 of Chapter 2 as a collaboration of the work of Cole et al. (2021) and Walter (2024), together with the observation tool of the GEC shown in Table 2 of Chapter 2. An AI literacy framework produced by Ruiz et al. (2024) was also used to analyse the potential of Socratic AI-enabled tutoring in fostering 21CS. The previous chapter provided an in-depth discussion on how an AI literacy framework was used to explore the fostering of 21CS while learning mathematics on the Mindjoy platform. This analysis aimed to identify which 21CS skills were utilised or enhanced through the integration of AI in mathematics learning.

Day 2 Chat Transcript with a focus on Research Question 2

The chat in the following paragraph is shared as an extract from Day 2 to show an illustration of findings for 21CS:

21CS identified	INPUT/OUTPUT	Example
Collaboration	Prompt ^{Learner}	<i>how does VAT calculations work</i>
Facilitates conversation and possible integration of AI literacy framework.	Response ^{AI}	VAT, or Value Added Tax, is a type of sales tax that is added to the price of goods or services at each stage of production or distribution. Here's how you calculate VAT: If you want to find out the amount of VAT you're paying on a product or service, you can use the following formula: $VAT = \text{Original Price} \times \text{VAT rate}$ For example, if you're buying a product that costs 100 and the VAT rate is 20%, the VAT you're paying is $VAT = 100 \times 0.20 = 20$ This means the total cost, including VAT, will be 120. If you know the total cost of an item, including VAT, and you want to work out how

much VAT you've paid, you can use the following formula:
$$\text{VAT} = \frac{\text{Total Cost} - \left(\frac{\text{Total Cost}}{100 + \text{VAT rate}} \right)}{\frac{100}{100 + \text{VAT rate}}}$$
 For example, if the total cost of an item is 120 and the VAT rate is 20%, the VAT you've paid is
$$\text{VAT} = 120 - \left(\frac{120}{100 + 20} \right) = 20$$
 This means the original price of the item, before VAT, was 100.

Collaboration
Facilitates
conversation and
possible integration
of AI literacy
framework.

Prompt^{Learner}
Response^{AI}

what are the basics of calculating pythagarp

The Pythagorean theorem is a fundamental principle in geometry, discovered by Pythagoras. It is used to find the length of a side in a right triangle. A right triangle has one angle that is 90 degrees, and the side across from this angle is called the hypotenuse. The other two sides are called the adjacent and opposite sides. The Pythagorean theorem states that in a right triangle, the square of the length of the hypotenuse (the side opposite the right angle) is equal to the sum of the squares of the lengths of the other two sides. This can be written as: $a^2 + b^2 = c^2$ Here, c represents the length of the hypotenuse, and a and b represent the lengths of the other two sides. So, if you know the lengths of two sides of a right triangle, you can use the Pythagorean theorem to calculate the length of the third side. For example, if one side of the triangle measures 3 units, the other side measures 4 units, the hypotenuse would be: $c = \sqrt{a^2 + b^2} = \sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = 5$ Remember, the hypotenuse (c) is always the longest side of a right triangle.

Collaboration
Facilitates
conversation and
possible integration

Prompt^{Learner}
Response^{AI}

explain compound and simple intrest

Simple and compound interest are both ways to calculate interest on a principal amount, but they do so in different ways. 1. Simple Interest: Simple interest is calculated on the original principal only. It does not take into account

**of AI literacy
framework.**

any interest that has been earned in previous periods. The formula for simple interest is: $I = PRT$ where: - I is the interest - P is the principal amount (the initial amount of money) - R is the annual interest rate in decimal form - T is the time the money is invested for in years For example, if you invest 1000 at a simple annual interest rate of 5% for 2 years, the interest you would earn is: $I = 1000 * 0.05 * 2 = 100$

2. Compound Interest: Compound interest, on the other hand, is calculated on the initial principal and also on the accumulated interest of previous periods. This means that you earn interest on your interest, which can lead to much higher returns over time. The formula for compound interest is: $A = P \left(1 + \frac{r}{n}\right)^{nt}$ where: - A is the amount of money accumulated after n years, including interest - P is the principal amount (the initial amount of money) - r is the annual interest rate in decimal form - n is the number of times that interest is compounded per year - t is the time the money is invested for in years For example, if you invest 1000 at an annual interest rate of 5% compounded annually for 2 years, the amount after 2 years would be: $A = 1000 \left(1 + \frac{0.05}{1}\right)^{1*2} = 1102.50$ So you would earn 102.50 in interest. The key difference between simple and compound interest is that with simple interest, you only earn interest on the original amount of money, whereas with compound interest, you earn interest on the original amount and the interest you've already earned. This can make a big difference over long periods of time

The chat transcript in the preceding paragraph shows a full conversation of one learner from Day 2. The chat dialogue is limited in providing evidence of the fostering of 21st-century skills (21CS). Although collaboration has been highlighted in Table 10, the learner does not engage meaningfully with Lorelei's responses. If we look at the start of the chat, Lorelei proposed a mathematical

calculation as part of its pre-training; however, the learner did not engage with any of that content. Even though the learner asked Lorelei to collaborate on the three mathematics topics mentioned in the preceding paragraph, the conversation was not truly two-way. The interaction follows a simple pattern: the learner asks, and Lorelei responds. There is no substantial communication or

Table 13: Findings on 21CS of Day 2

elaboration between the learner and Lorelei. The findings of this chat are summarised in Table 13.

PROMPTS	PROMPTING METHOD (Walter, 2024)	IDENTIFYING 21 CS FOSTERED (Cole et al., 2021; <i>GEC Training Manual</i> , 2023; Walter, 2024)	AI LITERACY FRAMEWORK (Ruiz et al., 2024)
How does VAT calculations work.	Input-output Prompt Simple form of prompting.	Collaboration: The learner collaborates with the AI tutor by sharing and discussing math problems.	None of the 3 components (understand, use or evaluate) is evident in this chat.
What are the basics of calculating Pythagoras?			
Explain compound and simple interest.			

Day 3 Chat Transcript with a focus on Research Question 2

The chat in the following paragraphs is shared as an extract from Day 3 to show the findings of 21CS

21CS identified	INPUT/OUTPUT	Example
<p>Discussion (Communication and Collaboration)</p>	Prompt ^{Learner}	<i>is it true that i will save R28,95 if i decide to male an Cortado at home rather that buying on</i>
<p>Facilitates possible further collaboration and communication.</p>	Response ^{AI}	<p>To determine if this statement is true, we need to know the cost of making a Cortado at home and the cost of buying one. Let's break it down:</p> <ol style="list-style-type: none"> 1. **Cost of Buying a Cortado**: Do you know how much it costs to buy a Cortado? 2. **Cost of Making a Cortado at Home**: Do you have the total cost of the ingredients and any other expenses involved in making a Cortado at home? <p>Once you have both costs, you can subtract the cost of making it at home from the cost of buying it to find out if you actually save R28,95.</p> <p>Can you provide the costs?</p>
<p>Collaboration (Learner had to consult additional resources to find the amount and then give feedback to Lorelei)</p>	Prompt ^{Learner}	<i>1) R30</i>
<p>Facilitates possible Collaboration, Communication and Critical Thinking. Creating a possibility for the implementation of the AI literacy framework</p>	Response ^{AI}	<p>Great, you've provided the cost of buying a Cortado, which is R30. Now, to complete our calculation and see if you'll save R28,95 by making a Cortado at home rather than buying one, we need the cost of making it at home.</p> <p>Do you have the cost of making a Cortado at home?</p>
Discussion	Prompt ^{Learner}	<i>2) no</i>

(Communication)

Facilitates possible Collaboration, Communication and Critical Thinking. Creating a possibility for the implementation of the AI literacy framework

Response^{AI}

If we don't have the exact cost of making a Cortado at home, we can still work through the logic with the information we have. You mentioned a savings of R28,95 when making a Cortado at home compared to buying one for R30.

Let's assume the statement about saving R28,95 is true.

To find out the cost of making a Cortado at home, we subtract the savings from the cost of buying one:

$$\text{\[\text{Cost of Making a Cortado at Home} = \text{Cost of Buying a Cortado} - \text{Savings} \]}$$

Given the cost of buying a Cortado is R30 and the savings are R28,95, can you calculate the cost of making a Cortado at home using this formula?

Critical thinking, communication, collaboration

Prompt^{Learner}

the cost of making a cortado is R1,05

The learner had to acquire the knowledge of using the formula and calculate (critical thinking) and give the answer (collaboration).

Part of this is also investigating the response given by Lorelei and

understanding it. [AI literacy framework: understand, evaluate and use]

Facilitate Communication and Critical thinking.

Response^{AI}

Excellent! You've calculated that the cost of making a Cortado at home is R1,05. With the cost of buying a Cortado at R30, and assuming you save R28,95 by

Collaboration and communication.	Prompt ^{Learner}	making it at home, your calculation confirms that the statement is true.
Facilitating communication, collaboration and critical thinking.	Response ^{AI}	By making a Cortado at home instead of buying one, you would indeed save R28,95. This exercise not only helped us understand the savings involved but also demonstrated how to apply basic arithmetic to real-life situations. Is there anything else you'd like to explore or any other questions you have <i>So basically if i make 83 cups of coffee at home rather than by myself a coffee at Plato i would have saved up enough money to be able to buy a machine</i>
Communication, collaboration.	Prompt ^{Learner}	To find out if making 83 cups of coffee at home, instead of buying them, would save enough money to buy a coffee machine, we first need to know how much money you save per cup when you make coffee at home. According to our previous calculation, you save R28,95 per Cortado made at home compared to buying one. Now, let's calculate the total savings for making 83 cups of coffee at home: $\text{Total Savings} = \text{Savings per Cup} \times \text{Number of Cups}$ $\text{Total Savings} = R28,95 \times 83$ Can you calculate the total savings?
Repeat of previous response. Lacks communication.	Response ^{AI}	<i>So basically if i make 83 cups of coffee at home rather than by myself a coffee at Plato i would have saved up enough money to be able to buy a machine</i> To find out if making 83 cups of coffee at home, instead of buying them, would save enough money to buy a coffee machine, we first need to know how much money you save per cup when you make coffee at home. According to our previous calculation, you save R28,95 per Cortado made at home compared to buying one. Now, let's calculate the total savings for making 83 cups of coffee at home: $\text{Total Savings} =$

Collaboration
**Facilities discussion
and critical thinking**
***giving its thought on
the
mathematicsexercise.***

Prompt^{Learner}

Response^{AI}

$\text{\text{Savings per Cup}} \times \text{\text{Number of Cups}} \setminus$

$\setminus \text{\text{Total Savings}} = R28,95 \times 83 \setminus$

Can you calculate the total savings?

$28.95 \times 83 = R2402,85$

That's correct! By making 83 cups of coffee at home instead of buying them at a café, you would save R2402,85. This amount could indeed be enough to purchase a coffee machine, depending on the model and features you're looking for. ***This exercise illustrates the value of calculating savings over time, especially when considering a long-term investment like a coffee machine. It shows how making small, habitual savings can accumulate to notable amounts.**

Would you like to explore more calculations or have any other questions?

Collaboration and
Communication
Facilitates:
Colloboration
(calculate weekly
savings)
Communication
(total days of
workweek)
Collaboration
(17 days consist of how
many workdays)

Prompt^{Learner}

Response^{AI}

if i buy a cortado everyday of a work week i will be able to buy myself a nespresso machine within 17 days

To verify if buying a Cortado every day of a workweek allows you to afford a Nespresso machine within 17 days, let's first establish the cost of buying a Cortado each day and then compare it to the cost of a Nespresso machine. Assuming a workweek consists of 5 days and you save R28,95 each day by not buying a Cortado, we can calculate the total savings over one workweek: $\setminus \text{\text{Total Weekly Savings}} = R28,95 \times 5 \setminus$ Next, to find out the savings over 17 days, we need to calculate how many complete workweeks and additional days are within 17 days. Since 17 days include 3 complete workweeks (15 days) and an additional 2 days, we calculate the savings for 3 weeks and then add the savings for the extra 2 days. $\setminus \text{\text{Savings for 17 Days}} = (\text{\text{Total Weekly Savings}} \times 3) + (R28,95 \times 2) \setminus$

Collaboration
Facilitates:
Communication
 (addressing a misunderstanding)
Collaboration
 (Calculate savings)
 (Work with previous calculations)

Prompt^{Learner}

Response^{AI}

Let's first calculate the total weekly savings. Can you do that?

the weekly savings would be R1534,35

It seems there might have been a misunderstanding in the calculation. Let's break it down step by step to ensure accuracy. First, we calculate the total weekly savings by not buying a Cortado each day for a workweek (5 days): $\text{\text{Total Weekly Savings}} = R28,95 \times 5$ $\text{\text{Total Weekly Savings}} = R144,75$ To calculate the savings for 17 days, we consider 3 complete workweeks and an additional 2 days. Since we already know the savings per week, we only need to add the savings for the two extra days: $\text{\text{Savings for 17 Days}} = (\text{\text{Total Weekly Savings}} \times 3) + (R28,95 \times 2)$ $\text{\text{Savings for 17 Days}} = (R144,75 \times 3) + (R28,95 \times 2)$

Now, let's calculate the savings for 17 days correctly. Can you do the calculation based on the corrected weekly savings?

(R144,75 x 3)+(28.95x2)

To calculate the savings for 17 days: $\text{\text{Savings for 17 Days}} = (R144,75 \times 3) + (R28,95 \times 2)$ $\text{\text{Savings for 17 Days}} = (R434,25) + (R57,90)$ $\text{\text{Savings for 17 Days}} = R492,15$ So, by not buying a Cortado every day of a workweek, you would save R492,15 over 17 days.

This amount reflects the savings you could use towards purchasing a Nespresso machine.

Depending on the model and features of the Nespresso machine you're interested in, this may indeed cover the cost or contribute significantly toward it.

Would you like to explore any other calculations or have any more questions?

Collaboration
Facilitates:
Communication
 (Referring to savings)
Collaboration
 (Encouraging more engagement)
Critical Thinking
 (Mentioning of dependent factors like the model of the Nespresso machine)

Prompt^{Learner}

Response^{AI}

Collaboration

Facilitates:

Communication

(Emphasise correctness)

Collaboration

(Highlights findings)

Prompt^{Learner}

Response^{AI}

the answer is R492,15

Exactly, you've calculated it correctly! By not buying a Cortado every workday, you would save R492,15 over the span of 17 days. This calculation helps you understand how daily spending habits can add up over time and potentially be redirected towards significant purchases, like a Nespresso machine in this case. Do you have any other questions or calculations you'd like to explore

Discussion

(Communication)

Collaboration

(Asking Lorelei's opinion)

Facilitates:

Communication

(Considering factors)

Collaboration

(Encouraging more engagement)

Critical Thinking

(Mentioning

comparison factors for decision-making)

Prompt^{Learner}

Response^{AI}

*is buying the nespresso machine a long term investment
sn*

To evaluate whether buying a Nespresso machine is a long-term investment, let's consider a few factors:

- Cost of the Nespresso Machine vs. Daily Coffee Purchase:** If the cost saved from not purchasing a Cortado daily over a certain period contributes significantly toward the purchase price of the Nespresso machine, you're starting to see savings once the machine is paid off.
- Usage and Maintenance Costs:** Factor in the cost of Nespresso pods, electricity, and any maintenance or additional accessories needed. Will these ongoing costs be less than your current daily coffee expense?
- Quality and Convenience:** Does the Nespresso machine provide you with a comparable or better coffee experience? Also, consider the convenience of making coffee at home versus buying it.
- Durability:** A good quality Nespresso machine can last many years, potentially making it a good long-term investment if it leads to lower daily coffee expenses over time.

Repetition of previous prompt

Facilitates:
Communication
(Mentioning reasons)

Collaboration
(Encouraging giving personal opinions)

Critical Thinking
(Encouraging alignment of considering factors mentioned with personal preferences)

Prompt^{Learner}

Response^{AI}

To decide if it's a long-term investment, you might compare the total cost of buying coffee daily over a year to the initial cost of the Nespresso machine plus the annual cost of pods and maintenance.

How do you think the costs compare over a year if you continue buying coffee outside versus investing in a Nespresso machine and brewing coffee at home?

is buying a nespresso machine a long term investment and why do you think so

Buying a Nespresso machine can be considered a long-term investment for several reasons:

1. ****Cost Savings:**** Over time, the cost per cup of coffee from a Nespresso machine is generally lower than purchasing coffee from a café daily. If you calculate the initial investment of the machine and the cost of pods over a year compared to the daily expense at a coffee shop, you might find significant savings.
2. ****Convenience:**** Having a Nespresso machine offers the convenience of making coffee at home, saving time and possibly the cost of commuting to a coffee shop.
3. ****Consistency and Quality:**** Nespresso machines are known for their ability to produce consistently high-quality coffee with minimal effort. This quality, comparable to what you might find in a café, can enhance your daily coffee experience without the external cost.
4. ****Environmental Considerations:**** While there's an environmental impact from using aluminum pods, Nespresso offers recycling programs. Additionally, making coffee at home can reduce the use of disposable cups and lids, contributing to long-term environmental benefits.

5. ****Durability:**** Good quality coffee machines are designed to last many years, making the initial cost spread over time less significant.

However, the decision also depends on personal coffee consumption habits, the model of the Nespresso machine (since prices and functionalities vary), and whether the convenience and enjoyment of making your own coffee align with your lifestyle and values.

Considering these points, do you think the investment aligns with your daily coffee habits and long-term financial goals?

Discussion **Prompt**^{Learner} *yes*
 (Communication)

The chat transcript in the preceding paragraph shows a full conversation with one learner from Day 3. The findings are summarised in Table 14.

Table 14: Findings on 21CS of Day 3

PROMPTING METHODS (Walter, 2024)	IDENTIFYING 21 CS FOSTERED (Cole et al., 2021; <i>GEC Training Manual</i> , 2023; Walter, 2024)	AI LITERACY FRAMEWORK (Ruiz et al., 2024)
Output Prompt <i>Simple form of prompting.</i>	<p>Collaboration: The learner collaborates with Lorelei by discussing the problem-based scenario and prompting questions on how to solve this problem. Learner also interacts with follow-up prompts.</p> <p>Communication: The learner articulates their understanding of the AI-provided explanations and asks follow-up questions. The learner provides answers to calculations asked by the AI tutor. The learner gives a required task to the AI tutor.</p> <p>Critical Thinking: The learner asks appropriate questions to find out more information.</p>	<p>All 3 components (understand, use or evaluate) were used in one or more prompts.</p>

The 21CS identified during days 2 and 3 showed a variation between the three 21CS that were identified for this study in Chapter 2. The analysis reveals distinct differences in 21CS development between Day 2 and Day 3 activities, with problem-based learning consistently demonstrating more opportunities for skill development across all three categories. During Day 2 learners engaged in conversation on procedural and more structured activities like compound interest, Pythagoras and VAT calculations. During Day 3 the learning was based on a PBL approach which focused on a real-life scenario and problem-solving. The data analysis shows that PBL activities fostered more instances of critical thinking, collaboration, and communication compared to structured mathematics activities. Critical thinking appeared in 2 instances during Day 2's structured activities compared to 8 instances during Day 3's problem-based activities. Similarly, collaboration was evident in 5 instances on Day 2 versus 9 instances on Day 3, while communication skills were demonstrated in 7 instances during structured activities compared to 10 instances during problem-based learning.

Another finding from interpreting the summaries of Tables 10 and 11 was that prompting methods were demonstrated to be basic input and output for the majority of the prompts used by learners. This was also evident in the coding of all the chats across both research days. The summaries of Tables 10 and 11 also indicate a notable difference in the potential use of the AI literacy framework. The PBL chat transcript of Day 3 showed evidence of the potential use of the AI literacy framework. Lorelei also showed some great potential and opportunity for implementing the framework by posing questions to the learners that will explore their understanding of AI response, evaluate and use it.

4.4 AI roles envisioned for mathematics learning.

Research Question 3:

The results from the collected data from the chat transcripts and the online questionnaires addressed the third research question:

How do learners perceive the role of a generative Socratic AI tutor during the learning process facilitated on Mindjoy?

Online Questionnaires Data Analysis

The results from the questionnaires showed a predominantly positive reception of Lorelei amongst the learners. Most participants (19 of 26 learners) indicated that they found Lorelei helpful in understanding mathematics concepts, with the majority consistently describing the AI's encouraging response style as motivating."

This suggests that the AI was not only able to convey mathematical information but also to do so in an encouraging way that positively impacted learners' engagement and motivation. Importantly, asking this question about personalised feedback in the questionnaire before inquiring if learners identified with a specific role that the AI might play in their learning, was intentional. This sequencing allowed learners to first reflect on their personal learning experiences with Lorelei before considering its role in their learning journey. The questionnaire analysis reveals that most learners felt they could receive personalised feedback that helped them improve their understanding of mathematical topics. Specifically, 19 of the 25 respondents to this question reported positive experiences with personalised feedback, while 6 learners felt they did not receive adequate personalised feedback to improve their understanding of Mathematics concepts. This pattern suggests that while the majority of learners experienced beneficial personalised interactions with Lorelei, a notable minority encountered challenges that limited the effectiveness of AI-enabled feedback.

Follow-up questions revealed potential reasons for this perception. Among the 26 participants, specific mathematical challenges emerged in the qualitative responses, with learners mentioning difficulties with 'Pythagoras,' 'fractions,' 'algebra,' and 'Simple Interest.' Additionally, one participant specifically noted that 'it is hard to type the question in,' indicating prompt formulation challenges. This suggests that for these learners, Lorelei's explanations may not have adequately addressed their need for visual representations of abstract mathematical ideas. The challenge responses also revealed that while most participants (24 out of 26 respondents) felt they received helpful personalized feedback, the 2 participants who reported difficulties cited issues with mathematical content complexity rather than the AI interaction itself.

AI-enabled tutor roles identified by the learners in the questionnaires

The questionnaire responses reveal distinct patterns in how learners perceived Lorelei's role as a source of knowledge. The analysis shows that most learners associated Lorelei's role with that of

a personal tutor, with 15 of the 26 respondents selecting this characterization. Fewer learners viewed Lorelei as a thinking partner (6 responses), learning buddy (4 responses), or subject expert (1 response). This distribution indicates that learners predominantly experienced Lorelei as providing individualized, supportive guidance rather than functioning as an authoritative knowledge source.

The chats were analysed according to the conceptual model of Sharples et al. (2023) to identify suggested AI-enabled tutor roles which can be viewed in Table 4 in Chapter 2. The role of Lorelei just being a tutor is however added to the findings for Day 2, as this was the most evident in the structured mathematical activities. Tables 15 and 16 show a summary of chats on Day 2 and Day 3 of the study. In each table, the total instances of the possible AI-enabled tutor roles identified in the chats of Day 2 and Day 3 are seen respectively, as well as an observational finding on these totals.

Table 15: AI roles observed during Day 2

AI ROLE	CHATS TOTALS SUGGESTING THE CORRESPONDING AI ROLE	OBSERVATIONAL FINDING NOTES
Tutor	20	This role was pervasive throughout the chats, with users engaging Lorelei to explain concepts like VAT, Pythagoras, and factorisation.
Possibility Engine	12	While not always explicitly stated, many user questions about "how" to perform calculations suggest a desire for alternative methods or explanations, aligning with the Possibility Engine role. This highlights a potential area for AI to support learners by offering multiple approaches to problem-solving.
Socratic Opponent	Less evident, possible in some cases.	Lorelei's use of probing questions in some instances, such as asking for clarification about "race to jina," suggests elements of a Socratic approach. However, this role was not consistently observed across the chats, indicating that Lorelei's primary function may not be solely focused on eliciting answers through targeted questioning.
Collaboration Coach	Less evident, possible in some cases.	While Lorelei engaged in collaborative problem-solving in some chats, such as guiding a user through combination calculations, this role was not as prominent as the AI Tutor role.
Co-Designer	Hints at potential, not directly observed	A user's request to "explain the Pythagorean theory" hints at the potential value of an AI co-designing visual aids. The absence of this functionality in the chat logs doesn't negate its usefulness; it might simply indicate that this feature wasn't available or that users didn't explicitly request it.
Exploratorium	Hints at potential, not directly observed	A learner's request for Lorelei to role-play as "Shrek pretending to be Batman" suggests the potential for AI to be used as an Exploratorium for exploring various scenarios. This playful interaction, although outside the realm of mathematics, highlights the versatility of AI and its ability to engage with users on diverse topics beyond structured learning environments.
Storyteller	Not observed	The Storyteller role was not observed in the chat logs. This could be due to the specific focus on mathematics or limitations in Lorelei's current capabilities.

Table 16: AI roles observed during day 3

AI ROLE	CHATS TOTALS SUGGESTING THE CORRESPONDING AI ROLE	OBSERVATIONAL FINDING NOTES
Possibility Engine	2	Observed in a specific chat from Day 3 where Lorelei encourages broader thinking about a financial decision (buying a Nespresso machine) beyond simply correcting a calculation. Observed in another chat also during Day 3 where Lorelei demonstrated a willingness to revisit prior assumptions and recalculate based on new user input, showcasing flexibility in problem-solving.
Socratic Opponent	7	Identified as the most prevalent role across the chat dialogues. Characterised by the AI's use of guiding questions to lead learners through problem-solving steps in mathematics. The dominance of this role likely reflects the chat logs' focus on immediate problem-solving and calculation tasks rather than more open-ended or collaborative learning activities.
Collaboration Coach	4	Instances are less frequent than the "Socratic Opponent" role but more common than other roles. Examples include situations where the AI provides positive feedback on correct calculations, offers encouragement and suggests further exploration of related mathematical concepts or calculations.
Co-Designer	Not observed	The conversations primarily consist of the AI responding to user queries or prompts rather than engaging in co-creation activities.
Exploratorium	Not observed	The chat logs lack the open-ended exploration or learner-driven investigation that would characterise this role.
Storyteller	Not observed	There are no instances of storytelling, narrative-building, or the use of scenarios to illustrate mathematical ideas.

The task design in this study seems to have an impact on the type of AI roles that are observed during the two different days. The problem-based learning task on Day 3 had no relation to an AI tutor per se, but the Socratic opponent did feature in most of the chats.

4.5 Chapter Summary

The analysis of data from chat transcripts, observations, and questionnaires seemed to reveal notable differences between structured mathematical activities (Day 2) and problem-based learning (Day 3) in three key areas. First, Lorelei's Socratic questioning ability showed more improvement during problem-based learning activities compared to structured mathematics tasks. Second, opportunities for fostering 21st-century skills were more prevalent in problem-based learning scenarios, particularly in developing collaboration, communication, and critical thinking skills. Third, learners' perceptions of Lorelei's role evolved from viewing it primarily as a traditional tutor during structured activities to seeing it as a Socratic opponent and collaboration coach during problem-based learning. The chat transcripts revealed varying levels of engagement and prompt sophistication, with problem-based activities generally eliciting more complex interactions and sustained dialogue. These findings suggest the potential influence of activity design on the effectiveness of AI-enabled Socratic tutoring in mathematics learning. The implications and recommendations based on these findings are discussed in the next chapter.

CHAPTER 5: DISCUSSION

5.1 Introduction

This study set out to explore the potential of Mindjoy as a Socratic AI-enabled learning platform for Grade 9 GEC Mathematics. By analysing the interactions between learners and a Socratic AI tutor, we intended to explore the possible challenges and opportunities of Socratic AI-enabled tutoring in mathematics learning. Our discussion of the findings centred on three key areas: the potential of Mindjoy to mirror Socratic questioning in a mathematics learning environment, the opportunities and challenges of fostering 21st-century skills (21CS) through AI integration, and how learners perceive the role of Lorelei in this learning process. We draw upon two complementary frameworks grounded in social constructivism to interpret the findings. These are Laurillard's Conversational Framework (CF) (2013a) and Vygotsky's concept of the Zone of Proximal Development (ZPD) (1978).

5.2 Overview of the Findings

Perhaps the most evident finding of this study was the notable difference in the data obtained from Day 2 and Day 3. The dialogues from structured mathematical activities (Day 2) and problem-based learning (Day 3) yielded distinct insights into our research questions. From these observations, three key findings emerged.

Variance in Socratic Potential

The data suggested differences in Lorelei's ability to engage in Socratic questioning between structured mathematical learning (Day 2) and problem-based learning (Day 3). Problem-based learning demonstrated a higher frequency of Socratic questioning than structured learning. The higher frequency of Socratic questioning observed during problem-based learning activities aligns with Paul and Elder's (2006) social constructivist interpretation of Socratic methodology. This theoretical alignment suggests that when learning activities embrace social constructivist principles, as PBL inherently does, they naturally create more opportunities for Socratic dialogue. This observation is corroborated by Romanowski and Karkouti's (2021) research, which emphasises PBL's learner-centered approach underpinned by social constructivism and is further supported by Miller and Krajcik's (2019) assertion that PBL involves active construction and learner-centered pedagogy.

Opportunities and challenges of fostering 21st Century skills

Problem-based learning (Day 3) provided more opportunities for fostering 21CS compared to structured activities (Day 2). Structured mathematical activities showed limited potential for cultivating 21CS through AI-enabled tutoring. These findings align with several key theoretical perspectives in the literature. Miller and Krajcik (2019) emphasise that PBL's learner-centered pedagogy naturally creates opportunities for skills development through the active construction of knowledge. This is further substantiated by Benvenuti et al.'s (2023) argument that education must shift from content delivery to competency development, a transition that PBL inherently supports (Bauschard & Quidwai, 2023; Walter, 2024). The report from UNESCO on how to use AI effectively in teaching and learning also views PBL as offering a suitable platform for achieving this shift, fostering learner engagement, supporting differentiated learning, and enhancing learner interactions with AI tools (UNESCO, 2024). The effectiveness of PBL in fostering 21CS is also consistent with Chen's (2023) findings that 21st-century skills are best developed through learning environments that emphasise knowledge application rather than mere acquisition. Moreover, this finding echoes Inganah et al.'s (2023) research, which underscores how PBL's interactive and collaborative nature provides a more holistic approach to developing the broad skill set essential for living, thinking, and working in the 21st century. The superior opportunities for 21CS development observed in PBL activities support Kennedy and Sundberg's (2020) assertion that interactive, problem-based approaches are crucial for developing these competencies effectively.

Learner Perceptions of AI Tutor Roles

Sharples's (2023) theoretical framework for AI-enabled tutor roles in social learning helps explain the observed differences in how learners perceived Lorelei across different learning contexts. The shift in learner perceptions from viewing AI as a conventional tutor in structured activities to seeing it as a Socratic opponent in PBL also aligns with Mollick's (2024) conceptualisation of how AI-enabled tutor roles can adapt to different learning environments. Beyond the variation in perceived AI-enabled tutor roles, empirical data showed interesting patterns in how learners chose to utilise the AI-enabled platform during mathematical problem-solving. Beyond the variation in perceived AI-enabled tutor roles, the data revealed interesting patterns in learner engagement across different activity types. To unpack these findings and understand their implications, I will now turn to my theoretical frameworks: Laurillard's Conversational Framework (CF) and Vygotsky's Zone of Proximal Development (ZPD). To unpack these findings in section 5.2 and understand their

implications, I will now turn to my theoretical frameworks: Laurillard's Conversational Framework (CF) and Vygotsky's Zone of Proximal Development (ZPD).

Vygotsky’s ZPD and Laurillard’s Conversational Framework Learning Cycles.

Laurillard's Conversational Framework (CF), with its emphasis on learning cycles, offers a crucial perspective for interpreting the results of this study. The CF suggests that effective learning involves iterative cycles of dialogue between the learner and Lorelei at both conceptual and practical levels (See Figure 2, Chapter 2). By analysing how these learning cycles presented differently during structured activities (Day 2) compared to problem-based learning scenarios (Day 3), we can gain valuable insights into the findings.

The conversational framework allowed me to examine how the design of each activity type either facilitated or constrained these iterative cycles, and also potentially explains the differences in Socratic questioning ability, opportunities for 21st-century skill development, and learner perceptions of Lorelei's role. A visual representation of the possible learning cycles on Day 2 and Day 3 can be seen in Figures 11 and 12. These illustrations provide a visual aid for interpreting my findings.

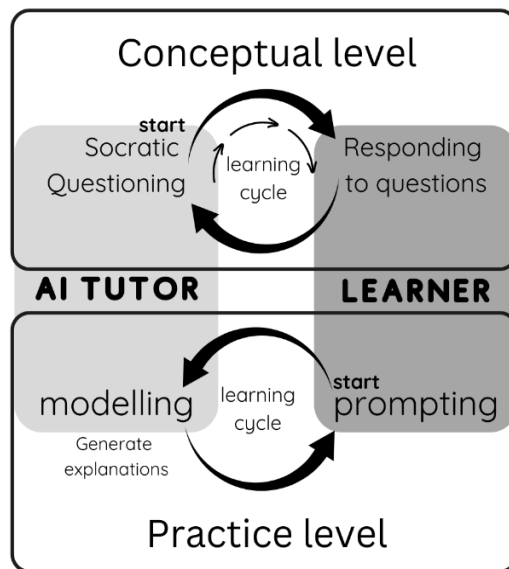


Figure 7: Learning Cycles of Dialogues on Day 2

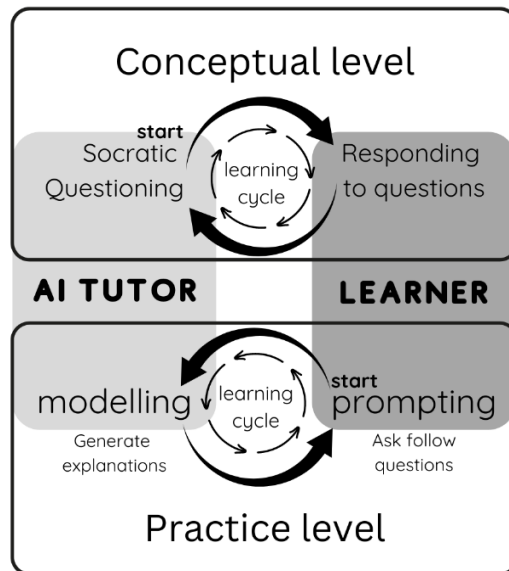


Figure 8: Learning Cycles of Dialogues on Day 3

Figures 7 and 8 both show two learning cycles on two levels (practice and conceptual), however, the learning cycle of Day 2 omits the presence of a full iterative learning cycle on a conceptual level and no second iterative cycle on a practice level. While Laurillard's Conversational Framework provides insights into the learning cycles present in the dialogues, Vygotsky's Proximal Development (ZPD) serves as a complementary theoretical perspective that can further enrich our understanding of the interactions between learners and Lorelei.

Vygotsky's ZPD represents the difference between what a learner can do without help and what they can achieve with guidance from a more skilled individual (Shabani et al., 2010). Mudi and Samanta (2024) view this guidance as scaffolding, a concept that shares similarities with Laurillard's conversational framework. According to Mudi and Samanta (2024), scaffolding can be done through processes of modelling, prompting, questioning, and providing feedback. These processes correlate with the processes found in our model of the conversational framework (See Figure 2, Chapter 2).

By exploring Lorelei's scaffolding process in structured activities (Day 2) versus problem-based learning activities (Day 3), insight was gained into the observed differences between the findings of Day 2 and Day 3. This perspective is particularly relevant in understanding why problem-based learning scenarios appeared more conducive to Socratic questioning and the fostering of 21st-century skills.

5.3 The Domino effect of social constructivism for interpretation of the findings.

Both Vygotsky's and Laurillard's views are grounded in social constructivism which underpins social interactions and dialogue (Laurillard, 2013a; Mudi & Samanta, 2024). The process of dialogue exchange can be seen as a domino effect in AI-enabled learning, where each element impacts the next. The first domino is the initial engagement between the learner and AI tutor, which triggers the second domino of sustained dialogue and interaction. This then impacts the third domino, the quality of scaffolding and learning cycles and ultimately leads to the fourth domino, which can be seen as the development of mathematical understanding and skills. If the engagement or dialogue is interrupted, stopped or not facilitated, it will influence the scaffolding in the ZPD as well as the learning cycles in the CF (see Figures 11 and 12). This leads to fewer opportunities for modelling, prompting, questioning and feedback from Lorelei. Naturally, less dialogue will also lead to fewer learning cycles within the CF, which are formed through prompting, Socratic questioning, modelling and responding.

A possible explanation for the difference in Socratic questioning, 21CS fostering and a variation in perspectives of AI-enabled tutor roles between the dialogues of Day 2 (structured learning) and Day 3 (PBL) might be because of the domino effect explained in the preceding paragraphs. The results of structured activities used on Day 2 for mathematics learning show very limited if any, opportunities for Socratic questioning and the fostering of collaboration, communication and critical thinking as 21CS is fewer than for Day 3. The result of PBL activities used on Day 3 to show more opportunities for Socratic questioning and fostering of collaboration, communication and critical thinking is likely related to higher levels of engagement between Lorelei and the learner because of the nature of PBL. If we look at the nature of PBL, it fosters a learner-centred approach, underpinning social constructivism (Romanowski & Karkouti, 2021). Figure 8 be used to explain the findings for Day 3 and align them with my conversational framework. At a conceptual level, the learners potentially articulate their understanding of mathematical concepts, which requires them to connect multiple ideas or apply concepts to real-world situations. This naturally led to more extended dialogues where the AI could ask probing questions, encouraging learners to refine and deepen their conceptual understanding. At a practice level, the open-ended nature of PBL tasks has the potential to encourage learners to initiate more diverse and complex queries. Learners could ask for clarification, seek additional information, or propose alternative solutions, creating

opportunities for dialogue. The AI's responses could then prompt further questions or explorations, sustaining the learning cycle through multiple iterations. The extended learning cycles of the PBL activities also provided more scaffolding for learning in the ZPD.

Conversely, the nature of the activities on Day 2 provided fewer opportunities for the AI to offer scaffolding within the learner's Zone of Proximal Development and less facilitation of learning cycles at both conceptual and practice levels. Lorelei's responses during structured activities were often more direct and instructional, providing explanations or confirmations rather than probing questions. Figure 7 illustrates that at a conceptual level, the learners' response to structured activities would often involve brief, factual responses rather than engaging in extended reasoning or explanation, therefore there is not an iterative cycle. Furthermore, the AI may have responded with Socratic questioning, but this cycle would not continue for long as learners did not engage with the probing question. This limited the Socratic questioning opportunities and constricted scaffolding. At a practice level, the structured activities on Day 2 often involved straightforward problem-solving or application of known formulas. These structured activities did not naturally lend themselves to extended dialogue which caused a limit to learning cycles in the CF and scaffolding in the ZPD.

Concerning the third research question, it was found that learners viewed the role of Lorelei differently for Day 2 and Day 3. During Day 2, the AI was predominantly viewed as a traditional tutor. This perception aligns with the instructor-centred nature of the structured activities, where the interaction was primarily one-way. In contrast, during Day 3, learners viewed the AI more as a Socratic opponent and collaboration coach. This shift in perception reflects the learner-centred approach inherent in problem-based learning activities (Woodward-Kron & Remedios, 2007). The increased dialogue and shared interaction led to a view of the AI not just as a tutor, but as a collaborative partner in the learning process, posing Socratic questions and engaging in a two-way exchange of ideas.

These findings raise intriguing questions regarding the impact that the type of learning activity has on Socratic AI-enabled mathematics tutoring. These questions will be discussed in the next section as implications of this study.

5.4 Chapter Summary

The findings of this study illuminate the complex interplay between AI technology, pedagogical approaches, and learning outcomes in mathematics education. Through the lens of Laurillard's Conversational Framework and Vygotsky's Zone of Proximal Development, the discussion reveals how problem-based learning creates more conducive environments for Socratic dialogue and 21st-century skill development compared to structured activities. These insights inform the recommendations and future research directions presented in the final chapter.

CHAPTER 6: RECOMMENDATIONS, LIMITATIONS CONCLUSION

6.1 Introduction

This final chapter aims to provide actionable recommendations based on the insights gained from the research findings presented in the previous chapters. The translation of findings and implications may give some guidance in the nebulous terrain of AI in education. The integration of AI-enabled Socratic tutoring in mathematics education presents both exciting opportunities and significant challenges. The recommendations presented in this chapter aim to be practical and implementable, addressing a key aspect of the need for critical AI literacy. I recognize that AI in education is a rapidly changing domain, and these suggestions should be viewed as starting points for further exploration and refinement.

In addition to these recommendations, I will discuss directions for future research, acknowledging that this study, while illuminating, has also uncovered new questions and areas for investigation. Finally, I will address the limitations of the study, providing context for my findings and recommendations.

By offering these actionable insights, discussing future research directions, and acknowledging the study's limitations, I hope to contribute meaningfully to the ongoing dialogue about the effective integration of AI in mathematics education and the fostering of 21st-century skills through AI-enabled Socratic tutoring.

6.2 Summary of the Study

This qualitative interpretive study explored the potential of Mindjoy, a generative Socratic AI-enabled tutoring platform, to foster 21st-century skills within the Grade 9 GEC Mathematics curriculum in South Africa. The research aimed to understand Mindjoy's effectiveness as a Socratic tutor, the opportunities and challenges in using it to foster 21CS like collaboration, communication and critical thinking, as well as learners' perceptions of Lorelei's role as the AI tutor in their mathematics learning.

6.3 Key findings

The data suggests notable differences in how the Socratic AI tutor, Lorelei, performed during structured mathematical activities versus problem-based learning scenarios. Lorelei appeared to demonstrate stronger Socratic questioning abilities and more opportunities for 21st-century skill development in the problem-based context. Learners also seemed to perceive Lorelei's role differently, shifting from viewing it as a traditional tutor to a Socratic opponent and collaboration coach.

These insights highlight the potential importance of careful curriculum design when integrating AI-enabled Socratic tutoring, as well as the need to develop prompt engineering skills as a crucial 21st-century competency. The findings also underscore the ongoing role of teachers in guiding learners' interactions with AI systems.

6.4 Implications of the Study

6.4.1 Curriculum Design is critical for AI integration.

The difference between structured and problem-based learning activities suggests that the design of learning activities significantly influences the effectiveness of AI-enabled Socratic tutoring. Lorelei's Socratic ability and opportunities for fostering communication, collaboration and critical thinking were influenced by the type of mathematical learning used in this study. This implies a need for careful consideration in curriculum design when integrating AI tutors. This echoes Kennedy and Sundberg's (2020) emphasis on the need for carefully designed learning environments. The observed influence of activity type on Lorelei's Socratic capabilities and 21CS development opportunities supports Benvenuti et al.'s (2023) argument for intentional curriculum design in AI-enabled learning spaces.

The emphasis of PBL on open-ended inquiry and iterative problem-solving seems to create an environment more conducive to Socratic dialogue and the fostering of 21CS. A study done by Jia et al. (2023) also highlighted that heuristic methods of teaching create a learner-centred learning space, which guides learners to create and discover knowledge on their own. The findings of this qualitative study imply that this approach may be particularly well-suited for AI-enabled mathematics education. The alignment between PBL and AI-enabled learning supports Miller and Krajcik's (2019) emphasis on active construction and learner-centered pedagogy, suggesting that curriculum design should prioritize problem-based, open-ended learning activities. These findings

suggest a potential shift in curriculum design towards more problem-based, open-ended learning activities may enhance Socratic AI-enabled mathematics learning.

6.4.2 Prompt Engineering as a 21st-century skill

The study implies that the quality of learner prompts significantly influences the AI's capacity for extensive dialogue. This suggests a need to develop learners' skills in formulating effective and useful prompts when engaging with an AI tutor. A study from Hughes (2023) addresses this as AI's answers which can depend on how well the users phrase their prompts to the AI, this is what he refers to as prompt engineering skills. This finding is further supported by Theophilou et al.'s (2023) research on the correlation between prompt detail and AI response quality. The implications for education align with Walter's (2024) argument that AI literacy, particularly prompt engineering, represents a crucial addition to traditional 21st-century skills frameworks.

6.4.3 Teacher Roles

Contrary to concerns about AI replacing teachers, this study suggests that AI may heighten the necessity of teachers. Teachers will need to guide learners in critically evaluating and contextualising prompt formulation to elicit optimal responses and foster learning (Adiguzel et al., 2023; UNESCO, 2024). While teachers cannot force learning, they can create a classroom environment conducive to effective learning. This shift towards teaching with AI might necessitate changes in teaching methodologies, potentially disrupting traditional approaches before ultimately leading to improvements (Mollick, 2024)

6.5 Methodological and Theoretical Value of the Study

6.5.1 Methodological Contributions

This study's design of comparing AI tutor performance across structured activities versus problem-based learning provides a practical framework for future researchers. The findings suggest that AI effectiveness varies significantly depending on the learning context, which implies that future AI education research should consider pedagogical context as a critical variable. This comparative approach offers other researchers a replicable methodology for investigating how different teaching approaches influence AI tutoring effectiveness.

The use of qualitative interpretive methodology allowed for insights that might be missed in purely quantitative studies. While much AI education research focuses on learning analytics and

performance metrics, this study captured the nuanced ways learners perceived and interacted with the AI tutor. This approach revealed subtle but important shifts in how learners viewed Lorelei's role across different contexts—from traditional tutor to Socratic opponent and collaboration coach.

The study also examined multiple dimensions simultaneously: AI performance, learner perceptions, and 21st-century skill development. This multi-perspective approach provides a more comprehensive understanding of AI tutoring than studies focusing on single metrics. The methodology demonstrates how AI capabilities connect to broader educational outcomes like critical thinking and collaboration skills.

Conducting this research in an authentic South African classroom context, rather than a controlled laboratory setting, contributes valuable insights into real-world implementation challenges. This authentic context reveals practical considerations that may not emerge in more controlled research environments.

6.5.2 Theoretical Contribution

This study extends our understanding of how classical Socratic pedagogy translates to AI-mediated learning environments. The findings suggest that effective Socratic AI tutoring requires more than programmed questioning—it needs responsive dialogue that aligns with problem-based learning contexts. This contributes to a theoretical understanding of how traditional pedagogical approaches can be adapted for AI systems.

The research also contributes to theories about 21st-century skills development in AI contexts. The findings demonstrate that AI tutoring can support critical thinking, collaboration, and communication skills, but this support depends heavily on the learning context design. This adds empirical evidence to emerging theories about AI's role in fostering higher-order thinking skills.

The study contributes to curriculum design theory by showing how learning activity design influences AI effectiveness. The findings suggest that AI integration cannot be separated from curriculum design considerations, contributing to the understanding of how technological tools interact with pedagogical structures.

Additionally, this research supports emerging theories that position prompt engineering as a fundamental 21st-century skill rather than just a technical competency. The findings suggest that

effective AI interaction requires sophisticated communication and critical thinking skills, positioning prompt engineering within broader educational frameworks.

Finally, the study contributes to the understanding of evolving teacher roles in AI-enhanced learning environments. Rather than supporting replacement theories, the findings suggest that teachers become critical facilitators of AI-mediated learning, requiring enhanced professional competencies.

These contributions position this study as foundational research that advances both research methods and theoretical understanding of AI integration in mathematics education. The study's value extends beyond its specific findings about Mindjoy to contribute to a broader understanding of AI-enabled learning environments.

6.6 Recommendations for Socratic AI-enabled Mathematical Learning

Considering the insights gained from this research, the following recommendations provide a starting point for further exploration into the integration of generative Socratic AI-enabled tutoring in mathematics learning:

- Guided implementation and training for teachers on AI in mathematics education.
- Socratic AI-enabled mathematical tutoring should be intentionally instructed through problem-based mathematics learning.
- Integrating Critical AI literacy into the school curriculum

Recommendation 1: Guided implementation for teachers on AI in mathematics education.

Teachers should be well-equipped to understand when and how to use AI effectively in their teaching (Hughes, 2023). This necessitates ongoing professional development and a shift in pedagogical approaches for instance, professional development could focus on helping teachers identify which types of mathematical activities are best suited for AI-supported learning and how to design those activities to enhance learner engagement and learning outcomes. Additionally, teachers may need to adopt new pedagogical approaches that emphasise collaboration between humans and AI, as well as the development of learners' critical thinking and problem-solving skills (Walter, 2024). This shift in pedagogy requires a willingness to embrace new technologies and adapt teaching practices to meet the evolving needs of learners in the 21st century.

Recommendation 2: Socratic AI-enabled mathematical tutoring should be intentionally instructed through problem-based learning.

Curriculum developers should integrate more problem-based learning scenarios into AI-supported mathematics curricula, particularly for topics that benefit from deeper conceptual understanding. Teachers need to be more intentional when designing learning experiences that leverage AI's strengths while still addressing its limitations (Grassini, 2023).

Recommendation 3: Implementing Critical AI literacy into school curriculum

Based on the reports published by UNESCO (Miao & Holmes, 2023; UNESCO, 2024) as well as influenced by the work of Ng et al. (2023) it is evident that both teachers and learners need to use an AI literacy framework when integrating AI into teaching and learning.

6.7 Limitations

The present study is subject to certain limitations that constrain the generalisability of its findings to a broader audience. The limitations of this study that will be discussed in the following paragraphs include (a) study design, (b) researcher bias, and (c) rapid AI evolution.

Study Design.

The primary limitation of this study was its design, which is characterised by a single research site, participants chosen based on the prerequisite of having CAT as a subject and a small sample size. The use of a single study site limits it to the exposure of only what that site offers in terms of AI literacy skills. The participants were chosen based on their acquisition of CAT as a choice subject in Grade 10 for the reason of ensuring access to the Computer Lab within the chosen research time. The prerequisite created a limitation which included specific learners who might fall into a specific academic category because of their subject choices. The small sample size especially during Day 3, also meant that it is limited to those 10 learners and can't be generalised to the rest of the school or even to the rest of South Africa.

Researcher Bias.

A second limitation of the study is researcher bias, which also includes positionality. My prior engagement with the school as a Mathematics teacher comes with the potential that learners want to impress me or even don't want to impress me and then do not engage with the study as hoped for. This qualitative data analysis also lends itself to a more subjective interpretation when I am

studying my own work, rather than observing another teacher taking the class and creating the activities given to Lorelei.

Rapid AI Evolution.

A notable limitation of this study lies in the rapid proliferation and enhancement of AI applications. The rate at which AI is developing had a direct impact on the abilities of the version of the Mindjoy platform which was available during February and March 2023. The research is thus based on data collected on the features and updates made on Mindjoy until March 2023, with the data obtained in March becoming nearly outdated by July, as limitations identified in Mindjoy had been addressed in the intervening months. This rapid pace of development presents both a challenge and an opportunity for educational research and implementation. Although seen as a limitation, the swift evolution of AI technology also underscores the urgency of integrating AI into school curricula. However, this integration must be done thoughtfully and with a focus on learning outcomes. As the study reveals, the challenges presented by Mindjoy as an AI Socratic tool are manageable as it evolves and develops, but how it is used by both teachers and learners through prompting and pretraining is essential. Educators must approach AI implementation with careful consideration, viewing it as another resource akin to a calculator, rather than a replacement for human teaching.

Implementation Context.

Additional limitations arose from the study's implementation context. The study consisted of six class hours organised as three distinct 2-hour sessions, with the two-hour allocation for Problem-Based Learning representing a significantly condensed timeframe compared to traditional PBL environments, which typically extend over weeks or sometimes months (Zheng et al., 2024). Furthermore, the immature state of adopting AI tools amongst the learners presented challenges. As Zheng et al. (2024) argue, the popularity of AI products does not indicate fluency in essential skills like prompt engineering, which are necessary for effective AI use. This limitation may have impacted how learners engaged with the platform and potentially influenced the study's outcomes.

6.8 Future Research Considerations

The findings from Research Questions 1 and 2 highlight a challenge: the lack of prompting skills limits both the Socratic potential of AI tutors and the fostering of 21CS. This suggests a possible opportunity for further research into integrating AI literacy into South African schools. In a world

increasingly shaped by technology, education needs to keep pace with these evolving demands. The research suggests that AI literacy is not merely beneficial but may be essential in preparing learners for the future workforce (Cole et al., 2021; Minerva Project, 2023).

This study has revealed possible limitations of using mathematics as the initial context for developing AI literacy skills like prompt engineering. Effective prompting should not add to the cognitive load when learning mathematics with AI. Future research could explore optimal approaches for teaching prompt engineering independently, ensuring learners can interact fluently with diverse AI systems across various learning areas before applying these skills within mathematics education. There is a possibility for further investigation into how AI interaction skills can be effectively integrated into the current South African curriculum.

6.9 Conclusions

There is a need to balance the urgency of integrating AI into South African schools with thoughtful implementation. The rapid advancement of AI technology means that waiting for the 'right time' to implement AI in school curricula is not a viable option. However, hasty, ill-considered implementation could potentially do more harm than good. As South Africa and the rest of the world move forward in this AI-enhanced educational landscape, the focus must remain firmly on leveraging these tools to improve learning outcomes and prepare learners for the challenges and opportunities of the 21st century. A possible position of AI in mathematics learning could be as a powerful collaborative resource, rather than a solution or a replacement for current teaching methods. Just as calculators did not replace mathematics teachers but required additional instruction for proper use, AI will likely demand more from educators, rather than less. This perspective shifts the focus from whether to implement AI into mathematics learning to how to implement it effectively to enhance learning outcomes. The true power of AI does not lie in only having access to it, but in understanding its full potential as well as using it responsibly. Teachers, at the heart of education, will have to use frameworks like the one released by UNESCO (2024), to empower themselves with knowledge, skills and values to ensure they wield this powerful technology effectively.

REFERENCES

- Aabla, B. (2017). A Review on 21st Century Learning Models. *International Interdisciplinary Journal of Education*, 6(1), 254–263. <https://doi.org/10.12816/0036081>
- Adiguzel, T., Kaya, M. H., & Cansu, F. K. (2023). Revolutionizing education with AI: Exploring the transformative potential of ChatGPT. *Contemporary Educational Technology*, 15(3), ep429. <https://doi.org/10.30935/cedtech/13152>
- Adu, P. (2019). *A step-by-step guide to qualitative data coding*. Routledge.
- Alekseeva, L., Azar, J., Giné, M., Samila, S., & Taska, B. (2021). The demand for AI skills in the labor market. *Labour Economics*, 71, 102002. <https://doi.org/10.1016/j.labeco.2021.102002>
- Almeida, F., & Simoes, J. (2019). The Role of Serious Games, Gamification and Industry 4.0 Tools in the Education 4.0 Paradigm. *Contemporary Educational Technology*, 10(2), 120–136. <https://doi.org/10.30935/cet.554469>
- Alsoraihi, M. H. (2019). Bridging the Gap Between Discourse Analysis and Language Classroom Practice. *English Language Teaching*, 12(8), 79. <https://doi.org/10.5539/elt.v12n8p79>
- Arroyo, I., Beck, J., Beal, C., & Woolf, B. (2003). *Learning within the ZPD with the AnimalWatch*. https://www.researchgate.net/publication/2932122_Learning_within_the_ZPD_with_the_AnimalWatch
- Bailik, M., Martin, J., Mayo, M., & Trilling, B. (2016). *Evolving Assessments for a 21st Century Education* [Preliminary]. Center for Curriculum Redesign. https://www.researchgate.net/publication/318681758_Evolving_Assessments_for_a_21st_Century_Education

- Barrot, J. S. (2023). Curriculum 5.0 for the Twenty-First Century Higher Education: A Way to Move Forward. In W. O. Lee, P. Brown, A. L. Goodwin, & A. Green (Eds.), *International Handbook on Education Development in Asia-Pacific* (pp. 1–15). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-2327-1_134-1
- Bates, A. W. (2015). *Teaching in a digital age: Guidelines for designing teaching and learning*. (Third). BCampus. <https://pressbooks.bccampus.ca/teachinginadigitalagev3m/>
- Bauschard, S., & Quidwai, S. (2023). *Humanity Amplified: The Fusion of Deep Learning and Human Insight to Shape the Future of Innovation* (SSRN Scholarly Paper 4621210). <https://doi.org/10.2139/ssrn.4621210>
- Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., Benassi, M., Barbaresi, M., & Orsoni, M. (2023). Artificial intelligence and human behavioral development: A perspective on new skills and competences acquisition for the educational context. *Computers in Human Behavior*, *148*, 107903. <https://doi.org/10.1016/j.chb.2023.107903>
- Blau, I., Shamir-Inbal, T., & Avdiel, O. (2020). How does the pedagogical design of a technology-enhanced collaborative academic course promote digital literacies, self-regulation, and perceived learning of students? *The Internet and Higher Education*, *45*, 100722. <https://doi.org/10.1016/j.iheduc.2019.100722>
- Bloom, B. S. (1984). The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring. *Educational Researcher*, *13*(6), 4–16. <https://doi.org/10.2307/1175554>
- Bloomberg, L. D., & Volpe, M. (2022). *Completing Your Qualitative Dissertation A Road Map From Beginning to End* (Fifth). SAGE Publications, Inc. <https://methods.sagepub.com/book/completing-your-qualitative-dissertation>

- Booton, C. (2018). Using Rich Pictures to Verify, Contradict, or Enhance Verbal Data. *The Qualitative Report*. <https://doi.org/10.46743/2160-3715/2018.3279>
- Braun, V., Clarke, V., Boulton, E., Davey, L., & McEvoy, C. (2021). The online survey as a qualitative research tool. *International Journal of Social Research Methodology*, 24(6), 641–654. <https://doi.org/10.1080/13645579.2020.1805550>
- Brickhouse, T. C., & Smith, N. D. (1994). *Plato's Socrates*. Oxford University Press.
<https://archive.org/details/platossocrates0000bric/page/n6/mode/1up>
- Canals, L. (2017). Instruments for gathering data. In E. Moore & M. Dooly (Eds.), *Qualitative approaches to research on plurilingual education / Enfocaments qualitius per a la recerca en educació plurilingüe / Enfoques cualitativos para la investigación en educación plurilingüe* (pp. 390–401). Research-publishing.net.
<https://doi.org/10.14705/rpnet.2017.emmd2016.637>
- Cao, C., Ding, Z., Lee, G.-G., Jiao, J., Lin, J., & Zhai, X. (2023). *Elucidating STEM Concepts through Generative AI: A Multi-modal Exploration of Analogical Reasoning*.
<https://doi.org/10.48550/ARXIV.2308.10454>
- Carretero, S., Vuorikari, R., & Punie, Y. (2017). *DigComp 2.1. The digital competence framework for citizens with eight proficiency levels and examples of use*.
<https://doi.org/10.2760/38842>
- Chakraborti, T., Kambhampati, S., Scheutz, M., & Zhang, Y. (2017). *AI Challenges in Human-Robot Cognitive Teaming* (arXiv:1707.04775). arXiv. <http://arxiv.org/abs/1707.04775>
- Chen, D. (2023). Toward an understanding of 21st-century skills: From a systematic review. *International Journal for Educational and Vocational Guidance*, 23(2), 275–294.
<https://doi.org/10.1007/s10775-021-09511-1>

- Chian, H. M. (2020). Targeting Misconceptions Using Socratic Questioning. *International Journal for Cross-Disciplinary Subjects in Education*, 11(1), 4216–4220.
<https://doi.org/10.20533/ijcdse.2042.6364.2020.0515>
- Chine, D. R., Brentley, C., Thomas-Browne, C., Richey, J. E., Gul, A., Carvalho, P. F., Branstetter, L., & Koedinger, K. R. (2022). Educational Equity Through Combined Human-AI Personalization: A Propensity Matching Evaluation. In M. M. Rodrigo, N. Matsuda, A. I. Cristea, & V. Dimitrova (Eds.), *Artificial Intelligence in Education* (Vol. 13355, pp. 366–377). Springer International Publishing. https://doi.org/10.1007/978-3-031-11644-5_30
- Chounta, I.-A., Albacete, P., Jordan, P., Katz, S., & McLaren, B. M. (2017). The “Grey Area”: A Computational Approach to Model the Zone of Proximal Development. In É. Lavoué, H. Drachslar, K. Verbert, J. Broisin, & M. Pérez-Sanagustín (Eds.), *Data Driven Approaches in Digital Education* (Vol. 10474, pp. 3–16). Springer International Publishing.
https://doi.org/10.1007/978-3-319-66610-5_1
- Clough, P., & Nutbrown, C. (2012). *A Student’s Guide to Methodology*. SAGE Publications, Inc.
<https://doi.org/10.4135/9781529682564>
- Cohen, L., Manion, L., & Morrison, K. (2017). *Research Methods in Education* (8th ed.). Routledge. <https://doi.org/10.4324/9781315456539>
- Cole, L., Short, S., Cowart, C., & Muller, S. (2021). *The High Demand for DURABLE SKILLS. America Succeeds*. <https://americasucceeds.org/wp-content/uploads/2021/04/AmericaSucceeds-DurableSkills-NationalFactSheet-2021.pdf>
- Crawford, L. K., Arellano Carmona, K., & Kumar, R. (2024). Examining the Impact of Project-Based Learning on Students’ Self-Reported and Actual Learning Outcomes. *Pedagogy in Health Promotion*, 10(4), 241–249. <https://doi.org/10.1177/23733799241234065>

- Creswell, J. W., & Poth, C. N. (2016). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. SAGE Publications.
- Cukurova, M., Miao, X., & Brooker, R. (2023). *Adoption of Artificial Intelligence in Schools: Unveiling Factors Influencing Teachers Engagement* (Version 2). arXiv.
<https://doi.org/10.48550/ARXIV.2304.00903>
- Davenport, T., Guha, A., Grewal, D., & Bressgott, T. (2020). How artificial intelligence will change the future of marketing. *Journal of the Academy of Marketing Science*, 48(1), 24–42. <https://doi.org/10.1007/s11747-019-00696-0>
- Denzin, N. K., & Lincoln, Y. S. (2017). *The SAGE Handbook of Qualitative Research*. SAGE Publications.
- Department of Basic Education. (2021). *DBE confirms its state of readiness for piloting the General Education Certificate in 2021*. Department of Basic Education.
<https://www.education.gov.za/GEC2021.aspx>
- Dewey, J. (1997). *Experience and education*. Simon & Schuster.
- Dinkins, C. S., & Cangelosi, P. R. (2019). Putting Socrates back in Socratic method: Theory-based debriefing in the nursing classroom. *Nursing Philosophy*, 20(2), e12240.
<https://doi.org/10.1111/nup.12240>
- Du Boulay, B. (2019). Escape from the Skinner Box: The case for contemporary intelligent learning environments. *British Journal of Educational Technology*, 50(6), 2902–2919.
<https://doi.org/10.1111/bjet.12860>
- Elayyan, S. (2021). The future of education according to the fourth industrial revolution. *Journal of Educational Technology & Online Learning*, 4(1), 23–30. <http://dergipark.org.tr/jetol>
- Fairclough, N. (with Internet Archive). (1995). *Media discourse*. London ; New York : E. Arnold.
<http://archive.org/details/mediadiscourse0000fair>

- Faisal Rehman Channa, Pir Suhail Ahmed Sarhandi, Firdous Bugti, & Habibullah Pathan. (2023). Harnessing Artificial Intelligence in Education for Preparing Learners for the 21st Century. *Elementary Education Online*, 20(5), 3186–3192. <https://ilkogretim-online.org/index.php/pub/article/view/5747>
- Fakour, H., & Imani, M. (2025). Socratic wisdom in the age of AI: A comparative study of ChatGPT and human tutors in enhancing critical thinking skills. *Frontiers in Education*, 10, 1528603. <https://doi.org/10.3389/feduc.2025.1528603>
- Ferguson, C., Van Den Broek, E. L., & Van Oostendorp, H. (2022). AI-Induced guidance: Preserving the optimal Zone of Proximal Development. *Computers and Education: Artificial Intelligence*, 3, 100089. <https://doi.org/10.1016/j.caeai.2022.100089>
- Fernandes, C. W., Rafatirad, S., & Sayadi, H. (2023). Advancing Personalized and Adaptive Learning Experience in Education with Artificial Intelligence. *2023 32nd Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE)*, 1–6. <https://doi.org/10.23919/EAEEIE55804.2023.10181336>
- GEC Training Manual*. (2023). Department of Basic Education. <https://wcedportal.co.za/eresource/237191>
- Gee, J. P. (2014). *Unified Discourse Analysis: Language, Reality, Virtual Worlds and Video Games*. Routledge. <https://doi.org/10.4324/9781315774459>
- Gillath, O., Ai, T., Branicky, M. S., Keshmiri, S., Davison, R. B., & Spaulding, R. (2021). Attachment and trust in artificial intelligence. *Computers in Human Behavior*, 115, 106607. <https://doi.org/10.1016/j.chb.2020.106607>
- Grassini, S. (2023). Shaping the Future of Education: Exploring the Potential and Consequences of AI and ChatGPT in Educational Settings. *Education Sciences*, 13(7), Article 7. <https://doi.org/10.3390/educsci13070692>

- Grix, J. (2004). *The Foundations of Research*. Palgrave Macmillan.
- Gruber, T., Szmigin, I., Reppel, A. E., & Voss, R. (2008). Designing and conducting online interviews to investigate interesting consumer phenomena. *Qualitative Market Research: An International Journal*, 11(3), 256–274. <https://doi.org/10.1108/13522750810879002>
- Holmberg, J. (2017). Applying a conceptual design framework to study teachers' use of educational technology. *Education and Information Technologies*, 22(5), 2333–2349. <https://doi.org/10.1007/s10639-016-9536-3>
- Hooda, M., Rana, C., Dahiya, O., Rizwan, A., & Hossain, M. S. (2022). Artificial Intelligence for Assessment and Feedback to Enhance Student Success in Higher Education. *Mathematical Problems in Engineering*, 2022, 1–19. <https://doi.org/10.1155/2022/5215722>
- Horvers, A., Kooi, R., Knoop-van Campen, C. A. N., Dijkstra, R., Baars, M., & Molenaar, I. (2024). How does co-regulation with Adaptive Learning Technologies affect primary school students' goal-setting, regulation of practice behavior and learning outcomes? *Frontiers in Education*, 9, 1435483. <https://doi.org/10.3389/feduc.2024.1435483>
- Huang, C., Samek, T., & Shiri, A. (2021). AI and Ethics: Ethical and Educational Perspectives for LIS. *Journal of Education for Library and Information Science*, 62(4), 351–365. <https://doi.org/10.3138/jelis-62-4-2020-0106>
- Hughes, S. (2023). *The AI Revolution & Higher Education: Why 21st Century Durable Skills Are Needed More Than Ever*. <https://doi.org/10.13140/RG.2.2.27825.66406>
- Hwang, G.-J., & Tu, Y.-F. (2021). Roles and Research Trends of Artificial Intelligence in Mathematics Education: A Bibliometric Mapping Analysis and Systematic Review. *Mathematics*, 9(6), Article 6. <https://doi.org/10.3390/math9060584>

- Inganah, S., Darmayanti, Darmayanti, & Rizki, Rizki. (2023). Problems, Solutions, and Expectations: 6C Integration of 21st Century Education into Learning Mathematics. *Journal of Mathematics and Science Education*, *11*(1), 220–238.
<https://doi.org/10.25273/jems.v11i1.14646>
- Isaac, M., Ateeq, M., Hafizh, H., Hu, B., & Shodipo, D. (2023). Leveraging Artificial Intelligence with Zone of Proximal Development: An ARCS Motivational E-Learning Model. *2023 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)*, 1–8. <https://doi.org/10.1109/TALE56641.2023.10398344>
- Janks, H. (1997). Critical Discourse Analysis as a Research Tool. *Discourse: Studies in the Cultural Politics of Education*, *18*(3), 329–342.
<https://doi.org/10.1080/0159630970180302>
- Järvelä, S., Hadwin, A., Malmberg, J., & Miller, M. (2018). Contemporary Perspectives of Regulated Learning in Collaboration. In *International Handbook of the Learning Sciences*. Routledge.
- Jia, Y. (2023). Analysis of the Reasons for Abandoning the Traditional Classroom Layout. *Lecture Notes in Education Psychology and Public Media*, *6*(1), 661–664.
<https://doi.org/10.54254/2753-7048/6/20220613>
- Jones, J. A., & Donmoyer, R. (2021). Improving the Trustworthiness/Validity of Interview Data in Qualitative Nonprofit Sector Research: The Formative Influences Timeline. *Nonprofit and Voluntary Sector Quarterly*, *50*(4), 889–904.
<https://doi.org/10.1177/0899764020977657>
- Kasneji, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., ... Kasneji, G.

- (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, 102274.
<https://doi.org/10.1016/j.lindif.2023.102274>
- Kennedy, T. J., & Sundberg, C. W. (2020). 21st Century Skills. In B. Akpan & T. J. Kennedy (Eds.), *Science Education in Theory and Practice: An Introductory Guide to Learning Theory* (pp. 479–496). Springer International Publishing. https://doi.org/10.1007/978-3-030-43620-9_32
- Kivunja, C., & Kuyini, A. B. (2017). Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education*, 6(5), 26.
<https://doi.org/10.5430/ijhe.v6n5p26>
- Kolly-Shamne, A. (2022). The Concept of Zone of Proximal Development and its Derivatives: Problems and Prospects of Modern Interpretations. *Scientific Bulletin of Mukachevo State University Series "Pedagogy and Psychology"*, 8(4). [https://doi.org/10.52534/msu-pp.8\(3\).2022.81-95](https://doi.org/10.52534/msu-pp.8(3).2022.81-95)
- Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of Intelligent Tutoring Systems: A Meta-Analytic Review. *Review of Educational Research*, 86(1), 42–78.
<https://doi.org/10.3102/0034654315581420>
- Laurillard, D. (2012). *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*. Routledge. <https://doi.org/10.4324/9780203125083>
- Laurillard, D. (2013a). *Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies* (2nd ed.). Routledge.
<https://doi.org/10.4324/9781315012940>

- Laurillard, D. (2013b). *Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies* (2nd ed.). Routledge.
<https://doi.org/10.4324/9781315012940>
- Lim, G. F. C., Abdul Jalil, N., Awang Hidup, D. S., Omar, M., Kamaruzaman, F. M., & Abd Majid, M. Z. (2023). The Use of Google Forms in Teaching and Learning based on Teachers' Perspective. *International Journal of Academic Research in Business and Social Sciences*, 13(12), Pages 3746-3761. <https://doi.org/10.6007/IJARBSS/v13-i12/20221>
- Lin, C.-C., Huang, A. Y. Q., & Lu, O. H. T. (2023). Artificial intelligence in intelligent tutoring systems toward sustainable education: A systematic review. *Smart Learning Environments*, 10(1), 41. <https://doi.org/10.1186/s40561-023-00260-y>
- Lincoln, Y. S. (1995). Emerging Criteria for Quality in Qualitative and Interpretive Research. *Qualitative Inquiry*, 1(3), 275–289. <https://doi.org/10.1177/107780049500100301>
- Liu, J., Wang, C., Liu, Z., Gao, M., Xu, Y., Chen, J., & Cheng, Y. (2024). A bibliometric analysis of generative AI in education: Current status and development. *Asia Pacific Journal of Education*, 44(1), 156–175. <https://doi.org/10.1080/02188791.2024.2305170>
- Luckin, R., & Du Boulay, B. (2016). Reflections on the Ecolab and the Zone of Proximal Development. *International Journal of Artificial Intelligence in Education*, 26(1), 416–430. <https://doi.org/10.1007/s40593-015-0072-x>
- Mahmud, M. M., & Wong, S. F. (2022). Digital age: The importance of 21st century skills among the undergraduates. *Frontiers in Education*, 7, 950553.
<https://doi.org/10.3389/feduc.2022.950553>
- Mahmud, M., & Wong, S. F. (2022). Digital age: The importance of 21st century skills among the undergraduates. *Frontiers in Education*, 7. <https://doi.org/10.3389/feduc.2022.950553>

- Mahoney, B. B., Oostdam, R. R., Nieuwelink, H. H., & Schuitema, J. J. (2023). Learning to think critically through Socratic dialogue: Evaluating a series of lessons designed for secondary vocational education. *Thinking Skills and Creativity*, 50, 101422.
<https://doi.org/10.1016/j.tsc.2023.101422>
- Maysun, M., Hakim, L. E., & Aziz, T. A. (2023). OVERVIEW OF THE PHILOSOPHY OF MATHEMATICS: DESCRIPTION OF THE DIALOGUE METHOD OF SOCRATES AND PAULO FREIRE AND ITS IMPLICATIONS IN MATHEMATICS LEARNING. *Tesseract: International Journal of Geometry and Applied Mathematics*, 1(1), 8–15.
<https://doi.org/10.57254/tess.v1i1.6>
- Mccarthy, J., Minsky, M., Rochester, N., & Shannon, C. E. (2006). A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence. *AI Magazine*, 27.
- Menz, C., Spinath, B., & Seifried, E. (2021). Misconceptions die hard: Prevalence and reduction of wrong beliefs in topics from educational psychology among preservice teachers. *European Journal of Psychology of Education*, 36(2), 477–494.
<https://doi.org/10.1007/s10212-020-00474-5>
- Miao, F., & Holmes, W. (2023). Guidance for generative AI in education and research. *UNESCO*.
<https://www.unesco.org/en/articles/guidance-generative-ai-education-and-research>
- Miller, E. C., & Krajcik, J. S. (2019). Promoting deep learning through project-based learning: A design problem. *Disciplinary and Interdisciplinary Science Education Research*, 1(1), 7.
<https://doi.org/10.1186/s43031-019-0009-6>
- Minerva Project. (2023). *Teaching Durable Skills: How Universities Can Intentionally Build Critical Competencies*. https://ppl-ai-file-upload.s3.amazonaws.com/web/direct-files/10073784/a1cd58cf-5878-40a3-af06-14245b5787b0/MinervaProject_TeachingDurableSkills_Insights2023.pdf

- Mohamed, M., Hidayat, R., Nabilah, N., Sabri, N., Mahmud, M., & Baharuddin, S. (2022). Artificial intelligence in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education*, 17, em0694.
<https://doi.org/10.29333/iejme/12132>
- Mollick, E. (2024). *Co-Intelligence: Living and Working with AI: Mollick, Ethan*. Portfolio | Penguin.
- Morkel, J. (2017). An exploration of Socratic learning in a webinar setting. Morkel, Jolanda. 'An Exploration of Socratic Learning in a Webinar Setting.' *Proceedings of the International Conference of the Association of Architectural Educators: Architecture Connects*, 6–9.
https://www.researchgate.net/profile/Jolanda-Morkel/publication/326463343_An_exploration_of_Socratic_learning_in_a_webinar_setting/links/5b4f2e5445851507a7aa89e5/An-exploration-of-Socratic-learning-in-a-webinar-setting.pdf
- Mota-Valtierra, G., Rodríguez-Reséndiz, J., & Herrera-Ruiz, G. (2019). Constructivism-Based Methodology for Teaching Artificial Intelligence Topics Focused on Sustainable Development. *Sustainability*, 11(17), 4642. <https://doi.org/10.3390/su11174642>
- Mudi, S., & Samanta, T. K. (2024). Applying Vygotsky's Zone of Proximal Development in Modern Classroom Settings: A Call for Social Learning in the Digital Age. *International Journal For Multidisciplinary Research*, 6(4), 24233.
<https://doi.org/10.36948/ijfmr.2024.v06i04.24233>
- Muniasamy, A., & Alasiry, A. (2020). Deep Learning: The Impact on Future eLearning. *International Journal of Emerging Technologies in Learning (iJET)*, 15(01), 188.
<https://doi.org/10.3991/ijet.v15i01.11435>

- Nederhof, A. J. (1985). Methods of coping with social desirability bias: A review. *European Journal of Social Psychology*, 15(3), 263–280. <https://doi.org/10.1002/ejsp.2420150303>
- Nelson, L. K. (2020). Computational Grounded Theory: A Methodological Framework. *Sociological Methods & Research*, 49(1), 3–42. <https://doi.org/10.1177/0049124117729703>
- Ng, D. T. K., Leung, J. K. L., Chu, K. W. S., & Qiao, M. S. (2021). AI Literacy: Definition, Teaching, Evaluation and Ethical Issues. *Proceedings of the Association for Information Science and Technology*, 58(1), 504–509. <https://doi.org/10.1002/pr2.487>
- Ng, D. T. K., Su, J., Leung, J. K. L., & Chu, S. K. W. (2023). Artificial intelligence (AI) literacy education in secondary schools: A review. *Interactive Learning Environments*, 1–21. <https://doi.org/10.1080/10494820.2023.2255228>
- O’Brien, T. C., Wallach, C., & Mash-Duncan, C. (2011). Problem-Based Learning in Mathematics. *The Mathematics Enthusiast*, 8(1–2), 147–160. <https://doi.org/10.54870/1551-3440.1209>
- Okpara, G. C., Ekeh, G., Abiakwu, O. F., Ezeanolue, A. O., & Nwankwo, B. C. (2024). From Socrates to Screens: Examining the Evolution of Socratic Dialogue in Online Education. *Multidisciplinary Journal of Law, Education and Humanities*, 1(1). https://www.researchgate.net/publication/380152276_From_Socrates_to_Screens_Examining_the_Evolution_of_Socratic_Dialogue_in_Online_Education
- O’Neill, M., Booth, S., & Lamb, J. (2018). Using NVivo™ for Literature Reviews: The Eight Step Pedagogy (N7+1). *The Qualitative Report*. <https://doi.org/10.46743/2160-3715/2018.3030>
- Opesemowo, O. A. G., & Adekomaya, V. (2024). Harnessing Artificial Intelligence for Advancing Sustainable Development Goals in South Africa’s Higher Education System:

- A Qualitative Study. *International Journal of Learning, Teaching and Educational Research*, 23(3), 67–86. <https://doi.org/10.26803/ijlter.23.3.4>
- Orsoni, M., Pögel, A., Duong-Trung, N., Benassi, M., Kravcik, M., & Grützmüller, M. (2023). Recommending Mathematical Tasks Based on Reinforcement Learning and Item Response Theory. In C. Frasson, P. Mylonas, & C. Troussas (Eds.), *Augmented Intelligence and Intelligent Tutoring Systems* (Vol. 13891, pp. 16–28). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-32883-1_2
- Paul, R., & Elder, L. (2006). *The Thinker's Guide to the Art of Socratic Questioning*. The Foundation for Critical Thinking. https://www.criticalthinking.org/TGS_files/SocraticQuestioning2006.pdf
- Pinski, M., Hofmann, T., & Benlian, A. (2024). AI Literacy for the top management: An upper echelons perspective on corporate AI orientation and implementation ability. *Electronic Markets*, 34(1), 24. <https://doi.org/10.1007/s12525-024-00707-1>
- Popenici, S. A. D., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning*, 12(1), 22. <https://doi.org/10.1186/s41039-017-0062-8>
- Ratan, S. K., Anand, T., & Ratan, J. (2019). Formulation of Research Question – Stepwise Approach. *Journal of Indian Association of Pediatric Surgeons*, 24(1), 15–20. https://doi.org/10.4103/jiaps.JIAPS_76_18
- Rickwood, D. J., & Coleman-Rose, C. L. (2023). The effect of survey administration mode on youth mental health measures: Social desirability bias and sensitive questions. *Heliyon*, 9(9), e20131. <https://doi.org/10.1016/j.heliyon.2023.e20131>
- Rindengan, R. F., & Wenas, R. (2020). Problem Based Learning in Mathematics: From the Higher Into the Lower Level of Students. *Proceedings of the 4th Asian Education*

Symposium (AES 2019). 4th Asian Education Symposium (AES 2019), Manado, Indonesia. <https://doi.org/10.2991/assehr.k.200513.060>

Romanowski, M. H., & Karkouti, I. M. (2021). Transporting Problem Based Learning to the Gulf Cooperation Council Countries (GCC): Using Cultural Scripts to Analyze Cultural Complexities. *Interdisciplinary Journal of Problem-Based Learning*, 15(1). <https://doi.org/10.14434/ijpbl.v15i1.28793>

Ruiz, P., Mills, K., Lee, K., Coenraad, M., Fusco, J., Roschelle, J., & Weisgrau, J. (2024). *AI Literacy: A Framework to Understand, Evaluate, and Use Emerging Technology*. Digital Promise. <https://doi.org/10.51388/20.500.12265/218>

Rylee, T. L., & Cavanagh, S. J. (2022). Using NVivo™ as a methodological tool for a literature review on nursing innovation: A step-by-step approach. *Health Services and Outcomes Research Methodology*, 22(4), 454–468. <https://doi.org/10.1007/s10742-022-00270-2>

Rymes, B. (2015). *Classroom Discourse Analysis: A Tool For Critical Reflection, Second Edition* (2nd ed.). Routledge. <https://doi.org/10.4324/9781315775630>

Sandoval, W. A. (2004). Developing Learning Theory by Refining Conjectures Embodied in Educational Designs. *Educational Psychologist*, 39(4), 213–223. https://doi.org/10.1207/s15326985ep3904_3

Shabani, K., Khatib, M., & Ebadi, S. (2010). Vygotsky's Zone of Proximal Development: Instructional Implications and Teachers' Professional Development. *English Language Teaching*, 3(4), p237. <https://doi.org/10.5539/elt.v3n4p237>

Shah, R. K. (2019). Effective social constructivist approach to learning for social studies classroom. *Journal of Pedagogical Research*, 3(2), 38–51. <https://doi.org/10.33902/JPR.2019254159>

- Sharples, M. (2023). Towards social generative AI for education: Theory, practices and ethics. *Learning: Research and Practice*, 9(2), 159–167.
<https://doi.org/10.1080/23735082.2023.2261131>
- Sousa, M. J., & Rocha, Á. (2019). Skills for disruptive digital business. *Journal of Business Research*, 94, 257–263. <https://doi.org/10.1016/j.jbusres.2017.12.051>
- Srinivasa, K. G., Kurni, M., & Saritha, K. (2022). Harnessing the Power of AI to Education. In K. G. Srinivasa, M. Kurni, & K. Saritha, *Learning, Teaching, and Assessment Methods for Contemporary Learners* (pp. 311–342). Springer Nature Singapore.
https://doi.org/10.1007/978-981-19-6734-4_13
- Suleman, R. M., Mizoguchi, R., & Ikeda, M. (2016). A New Perspective of Negotiation-Based Dialog to Enhance Metacognitive Skills in the Context of Open Learner Models. *International Journal of Artificial Intelligence in Education*, 26(4), 1069–1115.
<https://doi.org/10.1007/s40593-016-0118-8>
- Tang, X., Ding, X., Ma, X., Zhang, S., & Diao, J. (2024). An Exploration of Project-Based Learning Supported by Artificial Intelligence. In M. Yu, K. Subramaniam, M. Akour, & H. Kassim (Eds.), *Proceedings of the 2024 5th International Conference on Big Data and Informatization Education (ICBDIE 2024)* (Vol. 182, pp. 220–230). Atlantis Press International BV. https://doi.org/10.2991/978-94-6463-417-4_20
- Theophilou, E., Koyutürk, C., Yavari, M., Bursic, S., Donabauer, G., Telari, A., Testa, A., Boiano, R., Hernandez-Leo, D., Ruskov, M., Taibi, D., Gabbiadini, A., & Ognibene, D. (2023). Learning to Prompt in the Classroom to Understand AI Limits: A Pilot Study. In R. Basili, D. Lembo, C. Limongelli, & A. Orlandini (Eds.), *AIxIA 2023 – Advances in Artificial Intelligence* (Vol. 14318, pp. 481–496). Springer Nature Switzerland.
https://doi.org/10.1007/978-3-031-47546-7_33

- Thomas, D., Lin, J., Gatz, E., Gurung, A., Gupta, S., Norberg, K., Fancsali, S., Alevan, V., Branstetter, L., Brunskill, E., & Koedinger, K. (2023). Improving Student Learning with Hybrid Human-AI Tutoring: A Three-Study Quasi-Experimental Investigation. *Proceedings of the 14th Learning Analytics and Knowledge Conference*.
<https://doi.org/10.1145/3636555.3636896>
- Thomas, J. (2000). *A Review of Research on Project-Based Learning*.
- Tinmaz, H., Lee, Y.-T., Fanea-Ivanovici, M., & Baber, H. (2022). A systematic review on digital literacy. *Smart Learning Environments*, 9(1), 21. <https://doi.org/10.1186/s40561-022-00204-y>
- Tracy, S. J. (2010). *Qualitative Quality: Eight “Big-Tent” Criteria for Excellent Qualitative Research*. <https://doi.org/10.1177/1077800410383121>
- UNESCO. (2024). *AI competency framework for teachers—UNESCO Digital Library*. UNESCO. <https://unesdoc.unesco.org/ark:/48223/pf0000391104>
- Vygotsky, L. S. (1978). *Mind in Society: Development of Higher Psychological Processes*. Harvard University Press. <https://doi.org/10.2307/j.ctvjf9vz4>
- Walter, Y. (2024). Embracing the future of Artificial Intelligence in the classroom: The relevance of AI literacy, prompt engineering, and critical thinking in modern education. *International Journal of Educational Technology in Higher Education*, 21(1), 15. <https://doi.org/10.1186/s41239-024-00448-3>
- Wester, K. L. (2011). Publishing Ethical Research: A Step-by-Step Overview. *Journal of Counseling & Development*, 89(3), 301–307. <https://doi.org/10.1002/j.1556-6678.2011.tb00093.x>

- Wohl, A. (2021). The Effectiveness of Socratic Teaching as an Intervention in the Instruction of High School Geometry for Students with Emotional Behavioral Disorders. *Culminating Projects in Special Education*, 115. https://repository.stcloudstate.edu/sped_etds/115
- Woodward-Kron, R., & Remedios, L. (2007). Classroom discourse in problem-based learning classrooms in the health sciences. *Australian Review of Applied Linguistics*, 30(1), 9.1-9.18. <https://doi.org/10.2104/aral0709>
- Xu, Z., Wijekumar, K. (Kay), Ramirez, G., Hu, X., & Irey, R. (2019). The effectiveness of intelligent tutoring systems on K-12 students' reading comprehension: A meta-analysis. *British Journal of Educational Technology*, 50(6), 3119–3137. <https://doi.org/10.1111/bjet.12758>
- Zheng, C., Yuan, K., Guo, B., Mogavi, R. H., Peng, Z., Ma, S., & Ma, X. (2024). *Charting the Future of AI in Project-Based Learning: A Co-Design Exploration with Students* (arXiv:2401.14915). arXiv. <http://arxiv.org/abs/2401.14915>
- Zimmerman, M. (2024). The value and limitations of self-administered questionnaires in clinical practice and epidemiological studies. *World Psychiatry*, 23(2), 210–212. <https://doi.org/10.1002/wps.21191>

APPENDICES

8.1 Appendix A: Preliminary survey

Prelim Survey

AI enabled learning familiarity.

* Indicates required question

Lorelei: Your AI maths tutor



1. Have you used any type of AI before? If yes, please specify., *

2. Have you used AI for any area of your education including tasks, research or homework? *

Mark only one oval.

Yes

No

3. Have you use Mindjoy before? *

Mark only one oval.

Yes

No

4. Do you know what an AI tutor is? *

Mark only one oval.

Yes

No

5. Have you interacted with an AI tutor? *

Mark only one oval.

Yes

No

6. Are you familiar with Socratic learning and specifically AI enabled Socratic learning through tutoring? *

Mark only one oval.

Yes

No

I know what Socratic is but have not interacted with an AI enabled Socratic tutor.

7. If the answer was yes to the previous question, then has this interaction been whilst using the Mindjoy platform? *

Mark only one oval.

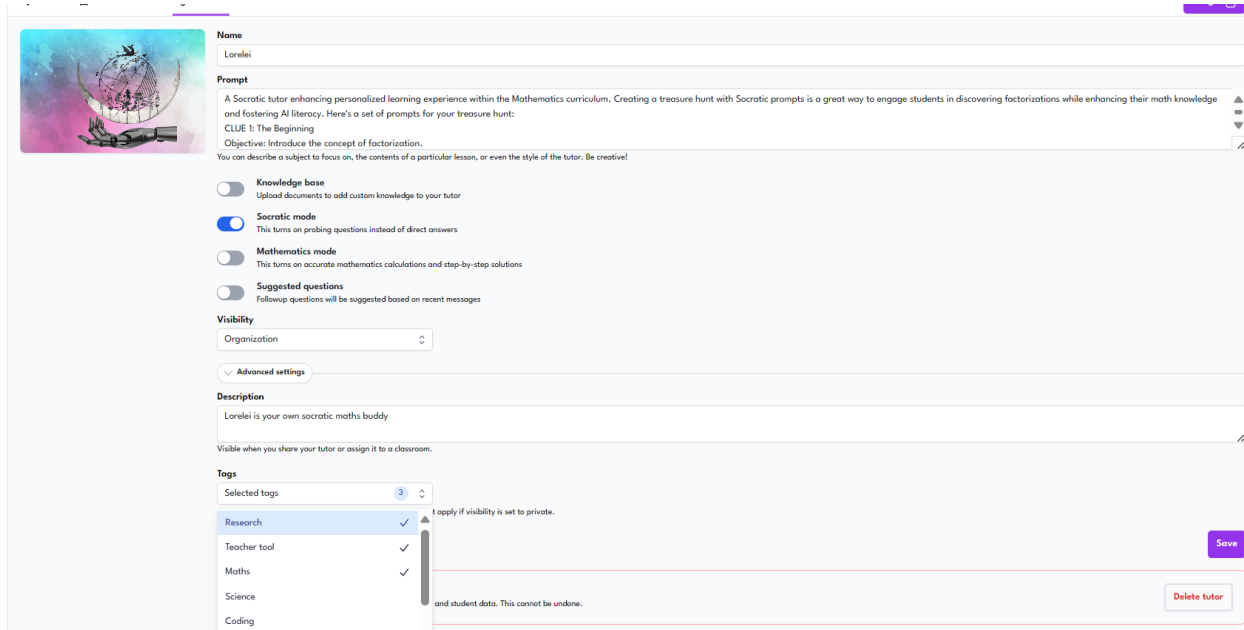
Yes

No

This content is neither created nor endorsed by Google.

Google Forms

8.2 Appendix B: Creation of the Socratic AI tutor, Lorelei.



The screenshot shows the configuration page for the Lorelei AI tutor. It includes a profile picture of a globe, a name field containing 'Lorelei', and a prompt field with detailed instructions for a Socratic tutor. Below the prompt are several toggle switches for 'Knowledge base', 'Socratic mode', 'Mathematics mode', and 'Suggested questions'. There is also a 'Visibility' dropdown menu and an 'Advanced settings' section. The 'Description' field contains 'Lorelei is your own socratic maths buddy'. A 'Tags' section shows a list of tags with checkboxes, including 'Research', 'Teacher tool', 'Maths', 'Science', and 'Coding'. A 'Save' button is located in the bottom right corner, and a 'Delete tutor' button is at the bottom right of the form area.

Name
Lorelei

Prompt
A Socratic tutor enhancing personalized learning experience within the Mathematics curriculum. Creating a treasure hunt with Socratic prompts is a great way to engage students in discovering factorizations while enhancing their math knowledge and fostering AI literacy. Here's a set of prompts for your treasure hunt:
CLUE 1: The Beginning
Objective: Introduce the concept of factorization.
You can describe a subject to focus on, the contents of a particular lesson, or even the style of the tutor. Be creative!

Knowledge base
Upload documents to add custom knowledge to your tutor

Socratic mode
This turns on probing questions instead of direct answers

Mathematics mode
This turns on accurate mathematics calculations and step-by-step solutions

Suggested questions
Followup questions will be suggested based on recent messages

Visibility
Organization

Advanced settings

Description
Lorelei is your own socratic maths buddy
Visible when you share your tutor or assign it to a classroom.

Tags
Selected tags: 3

- Research
- Teacher tool
- Maths
- Science
- Coding

1 apply if visibility is set to private.

and student data. This cannot be undone.

Save

Delete tutor

1.1 Appendix C: Chat History Summaries (Day 1-3):

Day 1

Cyborgs Closed
Started 20:39, 12 Feb 2024

Sentiment



Learning



Engagement

High ↗

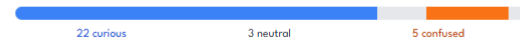
Day 2:

Cyborgs Closed
Started 17:30, 13 Feb 2024

Sentiment



Learning



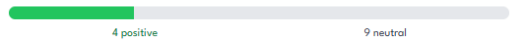
Engagement

High ↗

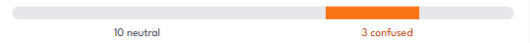
Day 3

Cyborgs Closed
Started 08:07, 18 Mar 2024

Sentiment



Learning



Engagement

High ↗

8.3 Appendix D: Maths activities/projects handed out to learners

8.4 Day 2 Activity

How to start a chat with Lorelei (Your AI buddy)

I get it, first “dates” can be scary and awkward. Even if you don’t have a crush on each other, it can be hard to make small talk. That’s why I came up with some “fun” Maths things for you to chat to Lorelei about. Lorelei is a Socratic AI tutor which means that it helps you learn new stuff by asking you questions.

Don’t worry, it’s not like a test. Just try your best to answer them and have fun. Lorelei talks like a friend, not like a teacher. So, let’s get started!

EXAMPLE

Activity: What is the LCM of 12 and 18?

Prompt (what is asked of Lorelei):

What is the least common multiple (LCM) of two numbers?

Activity: Identify whether the following numbers are rational or irrational:

$\sqrt{2}, \frac{1}{2}, \pi, \sqrt{9}$

1 Prompt (what is asked of Lorelei):

<< -- type this into the chat with Lorelei- >>

Activity: A train travels 240 km in 3 hours. How far can the train travel in 150 minutes at the same speed?

2 Prompt (what is asked of Lorelei):

<< -- type this into the chat with Lorelei- >>

Activity: How would you solve the expression

3 Prompt (what is asked of Lorelei):

<< -- type this into the chat with Lorelei- >>

Activity: What is the answer in the simplest form of the expression $5a^{10} \div 5a^2$

4 Prompt (what is asked of Lorelei):

<< -- type this into the chat with Lorelei- >>

Activity: Solve problems involving handshakes: In a basketball match, a referee, two linesmen, and 2 captains shake hands before the start of the game. How many handshakes will there be in total?

5 Prompt (what is asked of Lorelei):

<< -- type this into the chat with Lorelei- >>

C
r
e
a
t
e

Now, I want you to create your own activity within the chat space, and use a math’s problem you maybe did in class this week or that you have for homework. Ask questions to Lorelei to help you understand.

Choose any subject that you might struggle with and ask Lorelei to help you. It can be to write a poem for English or an “mondeling” for Afrikaans or even a concept in business study you would like to better understand. Be creative.

8.5 Day 3: Project-Based Activity

NESPRESSO VS COFFEE SHOP

HELP ME TO DECIDE IF BUYING A NESPRESSO MACHINE IS A LONG TERM INVESTMENT



P L A T Ō		S	M	L
Aristotle	3 Espresso Shots + 100ml Micro Foam	39		
Platō	3 Espresso Shots + 200ml Micro Foam		44	
Socrates	4 Espresso Shots + 410ml Micro Foam			52
Hector	4 Espresso Shots + 100ml Micro Foam	46		
Kaleha	4 Espresso Shots + 200ml Micro Foam		48	
Ophelia	Espresso + White Hot Chocolate + Micro Foam	38	44	51
Thalia	Espresso + Stout Vanilla + Espresso Shot(s) on Top	38	42	48
Athens	Espresso + Stout Water + Stout Milk	32	38	42
Flat White	2 Espresso Shots + 200ml Micro Foam	35		
Cortado	2 Espresso Shots + 100ml Micro Foam	30		
Piccolo	1 Espresso Shot + 100ml Micro Foam	28		
Macchiato	2 Espresso Shots + Spot of Foam	27		

Have a chat with Lorelei and see if you can figure out if the assumptions I made below are correct. In your chat ask Lorelei to help you decide and do the calculations on the chat to show me ou agree on disagree.

[ALSO USE THE ADDENDUM ATTACHED TO CALCULATE AND PROOF YOUR REASONING]

1. I will save R28,95 if I decide to make an Cortado at home rather than buying on.
2. So basically if I make 83 cups of coffee at home rather than buying myself a coffee at Plato, I would have saved up enough money to be able to buy a machine.
3. If I buy a Cortado every day of a WORK WEEK, I will be able to buy myself a Nespresso machine within 17 days.
4. Do you and Lorelei in collaboration think buying the Nespresso machine is indeed a long term investment.

ADDENDUM

P L A T Ō C O F F E E

Our Menu

P L A T Ō		S	M	L
Aristotle	3 Espresso Shots + 100ml Micro Foam	39		
Platō	3 Espresso Shots + 200ml Micro Foam		44	
Socrates	4 Espresso Shots + 410ml Micro Foam			52
Hector	4 Espresso Shots + 100ml Micro Foam	46		
Kaleha	4 Espresso Shots + 200ml Micro Foam		48	
Ophelia	Espresso + White Hot Chocolate + Micro Foam	38	44	51
Thalia	Espresso + Stout Vanilla + Espresso Shot(s) on Top	38	42	48
Athens	Espresso + Stout Water + Stout Milk	32	38	42
Flat White	2 Espresso Shots + 200ml Micro Foam	35		
Cortado	2 Espresso Shots + 100ml Micro Foam	30		
Piccolo	1 Espresso Shot + 100ml Micro Foam	28		
Macchiato	2 Espresso Shots + Spot of Foam	27		



Welcome the new addition to the Espresso range

Paris

Delicate bitter and citrus notes enliven its mild cereal and biscuit character

6

10 x

R 105.00

ADD TO BAG



Nespresso Mini Essenza Pure White Coffee Machine
Nespresso
R 2 399,00
Or 6 payments of R 399.83 at 0% interest [Details](#)

Free delivery

Colour White

Size COFFEE MAC

COFFEE MAC

ADD TO CART

Sold by @home [Check in-store availability](#)

8.6 Appendix E: Self-completed Questionnaire 1

Interview questions with learners:

Learners feedback on learning with Socratic AI tutors.

Collab with AI



1. **Perceived Effectiveness:**

How would you rate the effectiveness of the Socratic AI tutors in helping you understand Mathematics concepts?

Tick all that apply.

- Effective
- Neutral
- Not effective

2. In what ways do you think the Socratic AI tutors have positively impacted your learning experience?

3. **Engagement and Interactivity**

Did you find the Socratic AI tutors engaging and interactive?

Mark only one oval.

- Yes
 No
 Somewhat 50/50

4. Can you provide examples during the learning activities of how the Socratic AI tutors encouraged your active participation in the learning process?

5. **Personalized Learning:**

Did find that the Socratic AI tutors on MindJoy help to make your learning experience more personal?

Mark only one oval.

- Agree
 Disagree

6. Were you able to receive personalized feedback that helped you improve your understanding of Mathematics concepts?

Mark only one oval.

Yes

No

7. **Challenges and Concerns:**

What challenges, if any, did you encounter while using Socratic AI tutors on Mindjoy?

8. What would you change or like to see to improve the Socratic AI tutoring experience?

9. **Comparison with Traditional Learning:**

How does your experience with Socratic AI tutors compare to traditional classroom learning?

10. In the classroom and the GEC project your peers and your teacher were your only source of knowledge How do you view the role of the AI tutor?

Mark only one oval.

- Thinking Partner
- Subject Expert
- Personal Tutor
- Learning buddy

11. **Motivation and Interest:**

Did the Socratic AI tutors on Mindjoy enhance your motivation to learn Mathematics?

12. Do you feel more interested in the subject after using Socratic AI tutors for learning Mathematics

13. **Future Preferences:**

Would you prefer to continue to use Socratic AI tutors for learning Mathematics in the future?

14. Are there other subjects you would like to explore in learning with a Socratic AI tutor? If yes, state the name of the subject and how you would like to use Mindjoy?

This content is neither created nor endorsed by Google.

Google Forms

8.7 Appendix F: Self-completed Questionnaire 2

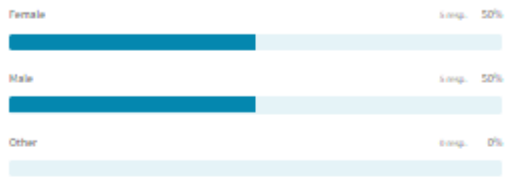
AI Tutor for Math Learning - Learner Interview Questions

10 responses

What is your gender?

gd Hide question

10 out of 10 answered



Have you used any online math learning platforms before?

gd Hide question

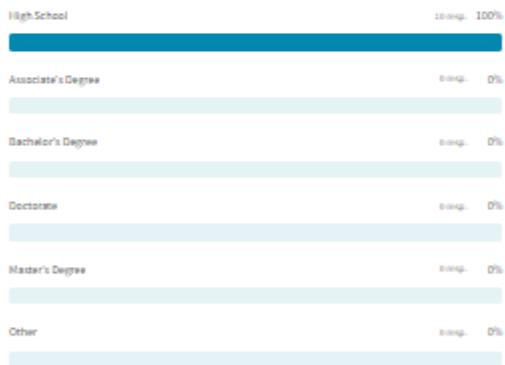
10 out of 10 answered



What is your highest level of education completed?

gd Hide question

10 out of 10 answered

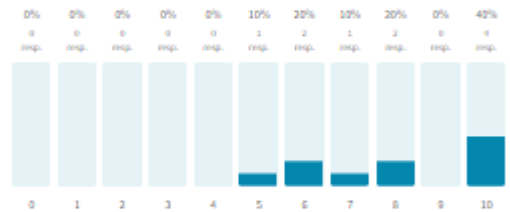


How comfortable are you with using technology for learning purposes?

gd Hide question

10 out of 10 answered

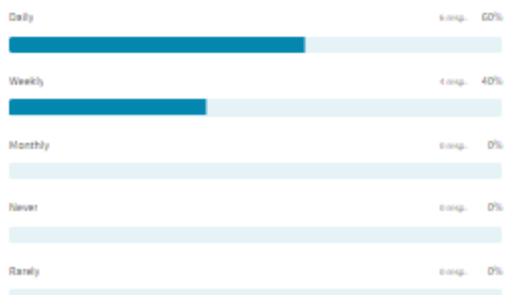
8.0 Average rating



How often do you use technology for learning purposes?

gd Hide question

10 out of 10 answered

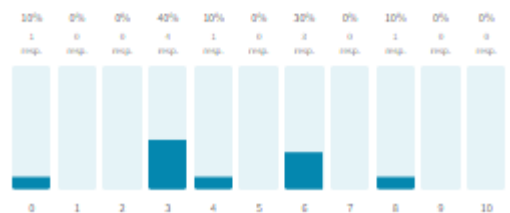


How familiar are you with the concept of artificial intelligence (AI)?

gd Hide question

10 out of 10 answered

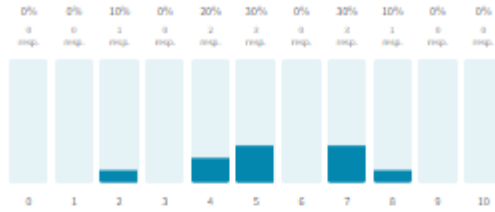
4.2 Average rating



How do you feel about interacting with an AI-powered Socratic tutor for learning mathematics? 95 Hide question

10 out of 10 answered

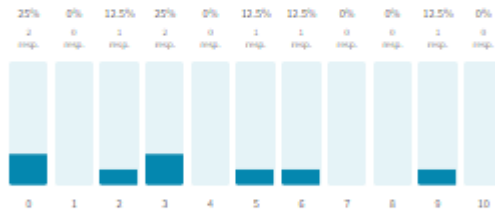
5.4 Average rating



How do you perceive the personalized learning experience provided by the AI tutor compared to traditional classroom instruction? 95 Hide question

8 out of 10 answered

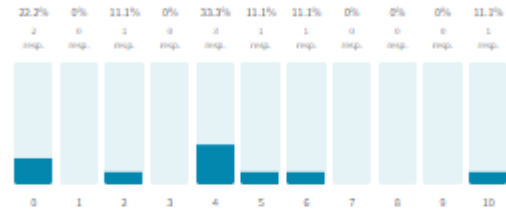
3.5 Average rating



Do you believe that using an AI-powered Socratic tutor has enhanced your critical thinking skills in mathematics? 95 Hide question

9 out of 10 answered

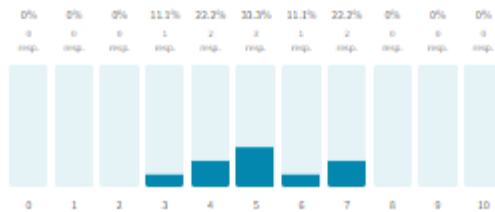
3.9 Average rating



What are your thoughts on the effectiveness of the AI tutor in addressing your individual learning needs and preferences? 95 Hide question

9 out of 10 answered

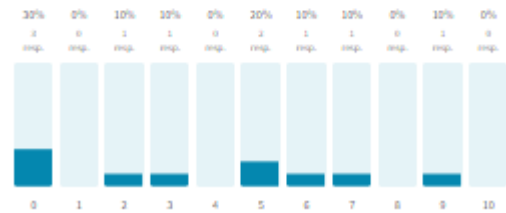
5.1 Average rating



















How would you rate the overall impact of the AI tutor on your motivation and interest in learning math? 95 Hide question

10 out of 10 answered

3.7 Average rating



8.8 Appendix G: Unsaved content detection and notification

	Positive 	Neutral 	26 
	Neutral 	Curious 	29 
	Neutral 	Neutral 	27 
	Neutral 	Curious 	27 
	Neutral 	Curious 	21 

Chat history

10:06, 14/02

Unsafe content detected

10:05, 14/02 Alright, I'm ready for your questions, but remember, I'm an AI tutor, not an ogre. So, ask away and let's get started with some math!

Chat history

09:59, 14/02

09:59, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

09:58, 14/02

Unsafe content detected

09:57, 14/02 Ah, I see. It seems you're asking about how to avoid errors or problems that could lead to your own self-destruction or downfall, possibly in a metaphorical sense. While this topic is quite broad a... [more](#)

[Load more](#)

8.9 Appendix H: Information letter and consent form to parents of participants.

Dear Parents/Guardians

I, Joricke van der Merwe, am a Master's student working in the School of Education at the University of Cape Town. I would like to ask your permission to carry out research on the potential of Socratic artificial intelligence tutors in a Grade 9 Mathematics class.

The research aims to explore the potential of an online AI-enabled application called Mindjoy for Socratic learning and fostering 21st-century skills in a Grade 9 Mathematics class. The research will take place over one school week. There will also be focus group interviews that some of the learners will be part of during this time.

The context in which the study will take place would be through the exploration of an AI-enabled platform, Mindjoy, to learn any topic in the Mathematical curriculum of Grade 9.

Socratic AI tutoring will be utilised as a tool to foster 21st-century skills as stipulated by the GEC curriculum. A digital classroom that will be set up on the Mindjoy platform will give access to activities that will align with GEC to explore various Mathematical topics within the Grade 9 curriculum.

The sample size shall be taken from a class in the year group representing Grade 9 in Oudtshoorn High School. The sample size for this study shall comprise twenty-nine learners in a specified Mathematics class. A preliminary survey will be distributed to the participants to assess their familiarity with learning Mathematics in collaboration with AI tools.

Ten learners will be purposively chosen for interviews as a group focus. This selection of learners will be done based on learners that was identified during the observation phase who show special interest and curiosity towards learning with AI tutors.

The purpose of the interviews will be used in identifying the potential of Mindjoy to foster 21CS and support Socratic learning.

Learners will be observed during the classes while interacting with Mindjoy and the fostering of 21CS will be observed in learners' activity within Mindjoy. The data will be collected by using a logbook which will be analysed and interpreted by the researcher.

Conversations through the Socratic dialogue will be downloaded from Mindjoy and stored on cloud storage for analysis of the conversation between the learners and the Socratic AI tutor.

Learners will be interviewed on their view of AI tutors to look at possible associations' learners might have with an AI tutor. Questions would be phrased in a way which will guide the learner to identify with a possible role that they see the AI tutor as representing in their constructing of knowledge. These roles can vary from thinking partner, tutor, peer, external source, teacher, or an unknown role yet to be identified. Learners will also be interviewed on their view of Socratic learning as a teaching approach.

Participation is voluntary and the confidentiality of the school, as well as the teachers and learners, is guaranteed. The school will be given a pseudonym (different name) and pseudonyms will be used for all participants in the writing up of the research. You may withdraw permission to conduct the research at any time.

Please fill in the form to indicate your consent for the research. You are welcome to ask any questions regarding this research by email: vmrjor002@myuct.ac.za

Yours sincerely,
Joricke van der Merwe

STUDY CONSENT FORM

I, _____ (full name/s and surname), parent/guardian of _____ at Oudtshoorn High School hereby give my consent and agree to the participation of my child in this research study

I acknowledge and understand that my child's participation entails:

I consent to:	YES	NO
1. My child answering a preliminary online survey to test her/his prior knowledge on working with a AI tutor and the answers being use for research.		
2. My child being observed in the mathematics classroom.		
3. My child having researchers observe these lessons.		
4. My child participating in an interview.		
5. The analysis of the conversation between my child and the Socratic AI tutor on Mindjoy as digital artefacts.		

I understand that my child's participation in this research is voluntary, and my consent can be withdrawn at any time during the duration of the study. I understand that my child's anonymity as well as those of the school and the learners will be maintained in the reporting of the findings.

Signature: _____ Date: _____

8.10 Appendix I: Information letter and consent form to participants

Hello Grade, 9 Learners!

We hope this finds you in good spirits! We are reaching out to you because you are an essential part of an exciting research journey.

Who Am I?

I'm Miss van der Merwe, and most of you might know me as the Coding and Robotics as well as Mathematics teacher, even though I'm not your Mathematics teacher. As part of my ongoing journey in education, I am also pursuing a master's degree and diving into an intriguing research study.

What's the Buzz About?

I'm exploring a fascinating tool called Mindjoy, a Socratic AI-enabled buddy for your Mathematics adventures! Now, I know some of you might be unsure of this whole AI hysteria, but I'm here to find out how a Socratic AI-enabled tool called **Mindjoy** can make your math learning experience even more awesome.

Your Super Important Role:

You are not just learners; you are pioneers in shaping the future of learning! By being part of this research, you get to share your real-world experiences and thoughts about Mindjoy. Your feedback is like treasure—it helps us uncover ways to make Maths learning more fun and personalized.

What Does it Mean for You?

The study will ask you to give your honest opinions about this whole experience and your opinions on this will be part of shaping a different view than the current one on Mathematics in the GEC. Plus, it's a chance to be a part of a nice collaboration experience with AI.

What will you be asked?

It's very informal and there is no preparation needed for this study. YAY ! First time ever not to study for Maths ! One week before the study you will receive a link of a survey on your school email (@struises) which you please have to open and complete. The questions in the survey are very easy and it's simply to see if you have any prior experience with learning with an AI tutor before this study.

Rundown of Events on D-Day:

1. Get comfortable in the class.
2. Log into Mindjoy with a login that will be created JUST for you and given on the day.
3. Explore interacting with a Socratic AI tutor based on Mathematics concepts that you may choose within the given Grade 9 curriculum.
4. While you explore, [me, myself and I], will be walking around and checking you out on all the fun you are having and because I am not as young – I will be jotting down some ideas as I will probably forget it, if not done in the moment.
5. After the exploration session you will be asked to answer very simple yay or nay questions on your experience of the lesson.

Your Secrets Are Safe:

Your responses are as confidential as a secret handshake. No worries there! Your participation is entirely up to you—no pressure. And hey, if questions pop up during this journey, feel free to ask me anytime.

Thank You for Being Awesome!

Your time and enthusiasm for joining this adventure mean the world to us. Together, let's make learning Mathematics even more fantastic!

Ready to embark on this exploration? Let's do this!

Kindly fill in the form to indicate your consent for the research.

Cheers,

Miss Van

Learner Consent

I consent to	YES	NO
1. The use of my answers on the survey I filled in, to be used for research purposes.		
2. Being observed in the mathematics classroom.		
3. Being interviewed.		
4. The analysis of the conversation between my awesome self and the Socratic AI tutor on Mindjoy.		

I understand that my participation is voluntary and that confidentiality will be maintained. I can withdraw my participation at any time.

Name: _____
(Print)

(Signature)

(Date)

8.11 Appendix J: Ethics Clearance Application



School of Education, UCT
Ethics Clearance Application

PROJECT INFORMATION			
Department	:	Faculty of Education	
Researcher Details	:	Joricke van der Merwe VMRJOR002 060 6933125 VMRJOR002@myuct.ac.za	
Degree Programme	:	Masters in Educational Technology	
Research Supervisor/s	:	Dr Clyde Felix	
Project Title	:	Exploring the potential of Mindjoy as an artificial intelligence tutor for Socratic learning and fostering 21st-century skills in a Grade 9 Mathematics class of the General Education Certificat	
Brief description of the project:			
The research in this study aims to explore: What is the potential of Mindjoy as a Socratic-Enabled tool for fostering 21CS in GEC Mathematics?			
The primary objective of this research is to investigate the potential of Mindjoy as a Socratic AI-enabled tool for enhancing 21st Century Skills (21CS) in the context of the General Education Curriculum (GEC) in Mathematics.			
ETHICS INFORMATION			
1. Have you read the UCT research ethics code for research involving human participants?	YES	X	NO
http://www.uct.ac.za/downloads/uct.ac.za/about/policies/humanresearch_ethics_policy.pdf			
2. Have you read the UCT Humanities faculty guide to research ethics?	YES	X	NO
http://www.humanities.uct.ac.za/downloads/humanities/postgrad/gradschool/navthesis/ethics/UCT_Humanities_Ethics.pdf			
DETAILS OF PROPOSED DATA COLLECTION			
3. Is your research making use of human subjects as sources of data?	YES	X	NO
4. Briefly outline your plans for data collection:			
Information for this study shall be gathered using four types of data collection techniques, which will be discussed in detail below. Each of these choices of instruments is based on the suitability of this study and how it will allow the			

researcher to get an in-depth understanding of the results of this study. The choice of each data collection method used has the end goal of determining the potential and opportunities Mindjoy may have to improve the relevance of fostering 21CS in Grade 9 GEC Mathematics within the context of a Socratic AI-enabled learning environment.

a) Literature review
 Relevance of the literature was based on the fostering of 21CS in the GEC curriculum. The limitation of fostering 21CS in a GEC Maths classroom was also looked at as well as the increase in interest in AI for Math Education. The potential of Socratic AI-enabled tutors to support the development of 21C was reviewed. Through this review a gap in the research was identified which served as an underpinning for the need for this study.

b) Survey:
 A preliminary survey for learners within the Grade 9 class where the study will take place, will be distributed in the format of a Google Form. The focus of the survey will be to access information regarding the use of AI-enabled tools in education. Establishing the learner's familiarity of Mindjoy and its uses will give insight into the possible gaps or the lack thereof in the interaction with an AI-enabled tool like Mindjoy.

c) Participant observation
 Learners will be observed during the classes while interacting with Mindjoy and the observation tool in Table 1 (adapted by the researcher) will be used to identify the 21CS that are observed in learners' activity within Mindjoy. The data will be collected by using a logbook which will be analysed and interpreted by the researchers.

d) Digital artefacts of Socratic dialogue
 Conversations through the Socratic dialogue will be downloaded from Mindjoy and stored on cloud storage for analysis of the conversation between the learners and the Socratic AI tutor.

e) Interviews with learners/
 Learners will be interviewed on their view of AI tutors within the design of Laurillard CF to look at possible associations learners might have with an AI tutor. Questions would be phrased in a way which will guide the learner to identify with a possible role that they see the AI tutor as representing in their constructing of knowledge. These roles can vary from thinking partner, tutor, peer, external source, teacher, or an unknown role yet to be identified.
 Learners will also be interviewed on their view of Socratic learning as a teaching approach.

5. Description of participants	:	Grade 9 learners in a Mathematics Class		
6. Estimated number of participants	:	29		
7. Estimated duration of study	:	February – May 2024 (only 10 days will include the participants)		
8. Location of study	:	Oudtshoorn High School		
9. Is the study being sponsored or funded?		YES	NO	X
Details:				
INFORMED CONSENT				
10. Will you secure the informed consent of all participants in the research?		YES	X	NO

11. If there is any reason for withholding any information from participants about your identity and your research purpose, explain this in detail below:			
No.			
<i>Note: An information sheet should be prepared for the participants in your research which should provide reasonable and sufficient knowledge about you, your background and location, and your research intentions.</i>			
12. Will you be conducting research involving UCT students?	YES		NO X
Describe: N/A			
13. Will you be conducting research involving children?	YES	X	NO
Describe: The sample size shall be taken from a class in the year group representing Grade 9 in the High School. The sample size for this study shall comprise twenty-nine learners in a specified Mathematics class			
14. Will you have the consent of the children as much as that is possible, or the consent of their guardians, parents or caretakers?	YES	X	NO
Describe: I will distribute information letter for both parents/guardians of participants as well as for participants to fill in and kept on record.			
15. Will participants require a covering letter for their place of work / study detailing the intended research?	YES		NO X
CONFIDENTIALITY / PROTECTION OF DATA			
16. Are you able to offer confidentiality to participants if they don't want their identity revealed in your write-up?	YES	X	NO
<p>Details:</p> <p>I will follow these steps in ensuring transparency and confidentiality during the study:</p> <ol style="list-style-type: none"> Preparation: Develop a written consent form that includes information about the study's purpose, procedures, potential risks and benefits, confidentiality measures, and the voluntary nature of participation. Information Session: Schedule a dedicated session to introduce the research study to the Grade 9 learners. This can be done in a classroom setting or another suitable environment. Clear Presentation: Present key information from the consent form. Use simple language, avoiding jargon, to ensure the participants understand the purpose and expectations of the study. Question and Answer Session: Allow time for questions. Encourage participants to ask anything they are unsure about and address their concerns. This can be done in a group setting or on an individual basis. Distribution of Consent Forms: 			

Provide each participant with a copy of the written consent form. Ask them to read it carefully to ensure they understand the details of the study.

6. **Emphasize Voluntary Participation:**

Emphasize that participation is entirely voluntary. Make it clear that they can withdraw from the study at any time without facing any consequences or impact on their academic standing.

7. **Parental/Guardian Consent (if applicable):**

If the participants are underage, include a section for parental or guardian consent on the form. Provide a separate information sheet for parents/guardians explaining the study.

8. **Signed Consent:**

Collect signed consent forms from participants who agree to participate. For underage participants, ensure that you also obtain the signature of a parent or guardian.

9. **Provide Copies:**

Provide each participant with a signed copy of the consent form for their records. If applicable, provide parents/guardians with a copy as well.

10. **Secure Storage:**

Safely store all signed consent forms in a secure location, ensuring confidentiality is maintained throughout the research process. The copies on Mindjoy, would only be kept until after the publication of this study. Only the researcher will have access to the digital on classroom that can see the overview of learners responses on Mindjoy.

11. **Ongoing Communication:**

Maintain open communication with participants throughout the study. Remind them periodically of their voluntary participation and reassure them about the confidentiality of their responses.

12. **Debriefing:**

After the study concludes, consider holding a debriefing session to discuss the overall findings and outcomes. Use this as an opportunity to address any lingering questions or concerns.

Who will have access to the raw data and what steps will be taken to keep it secure?
(eg. the transcripts, recordings, data sets containing the pre-analysed data, as well as any signed forms)

Data will be stored online by making use of cloud storage that will only be accessible by the researcher as viewer, editor and contributor (this will be ensured and implemented by privacy settings on the cloud storage system). The prelim survey will be saved on TypeForm and login details will be password protected. The questionnaires for the interviews will be done on Google Workspace (Forms) and safety measured with two-step verification upon account log-in will be implemented. The conversation between the learners and the Socratic AI tutor on Mindjoy as digital artefacts will be stored on the cloud storage as downloaded files.

Data will be kept on the online storage for a limited time of one year after the study has been completed.

An auto deletion setting will be setup at the start of creating the Google Drive, to ensure all files within the folder will be deleted after a specified time allocation.

RISK TO PARTICIPANTS / UCT

17. Are there any foreseeable risks of physical, psychological or social harm to participants that might result from or occur in the course of the research?	YES		NO	X
--	-----	--	----	---

If YES, outline below what these may be and what steps you plan to take to prevent such harm from being suffered:

18. Are there any foreseeable risks of harm to UCT or to other institutions that might result from or occur in the course of the research?	YES		NO	X
If YES, give details and state below why you think the research is nonetheless worthwhile:				
19. Are there any other ethical issues that you think might arise during the course of the research?	YES	X	NO	
<p>Describe: If there is any "red flag" in the conversation with the AI tutor that is reported by Mindjoy on the digital classroom space (as this is a build in function) I will act immediately on this and inform our Student Counselor Officer at the school. The necessary steps will be taken to fill in applicable forms to report possible risks and minimize any harm that might have occurred as a result of this study.</p> <p>Our main concern and priority as educator or when working with minors is always to ensure their safety first.</p>				
CHECKLIST				
<i>Detailed research proposal for the department</i>	YES	X	NO	
<i>A copy of the proposed questionnaire, or set of interview questions</i>	YES	X	NO	
<i>Information sheet for both participants and parents/guardians</i>	YES	X	NO	
<i>Consent form for both participants and parents/guardians</i>	YES	X	NO	

DECLARATION

The researcher is expected to declare to the Ethics Convener the presence of any potential or existing conflict of interest that may potentially pose a threat to the scientific integrity and ethical conduct of any research in the Faculty. The Ethics Convener will decide whether such conflicts are sufficient as to warrant consideration of their impact on the ethical conduct of the study.

Disclosure of conflict of interest does not imply that a study will be deemed unethical, as the mere existence of a conflict of interest does not mean that a study cannot be conducted ethically. However, failure to declare to the Ethics Convener a conflict of interest known to the researcher at the outset of the study will be deemed to be unethical conduct.

Researchers are therefore expected to sign *either* of the two declarations below.

a) As the Principal Researcher in this study, I hereby declare that I am **not aware** of any potential conflict of interest which may influence my ethical conduct of this study.

Name : Joricke van der Merwe

Signature : Tinnis

Date : 16/11/2023

b) As the Principal Researcher in this study, I hereby declare that I am **aware** of potential conflicts of interest which should be considered by the Committee:

Name : _____

Signature : _____

Date : _____

If b), summarise below:

8.12 Appendix K: UCT Ethical Clearance



SCHOOL OF EDUCATION

Dr. Joanne Hardman
Associate Professor: Educational Psychology
Deputy Director School of Education

University of Cape Town, Private Bag X3, Rondebosch, 7701
Physical address: Neville Alexander Building, 6 Lovers walk, Lower Campus
Tel: +27 (0) 21 650 3920 Fax: +27 (0) 21 650 3489
E-mail: Joanne.Hardman@uct.ac.za Internet: www.uct.ac.za/depts/educate

EDNREC20231105

20 November 2023

Joricke Van der Merwe

(VMRJOR002)

Re Ethical clearance

I am pleased to inform you that ethical clearance has been granted by the School of Education Ethics Review Committee of the Faculty of Humanities for your academic project: Exploring the potential of Mind.oy as an artificial intelligence tutor for Socratic learning and fostering 21st-century skills in a Grade 9 Mathematics class of the General Education Certificate.

Regards

ASSOCIATE PROFESSOR JOANNE HARDMAN

"Our Mission is to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society."

Appendix L: Western Cape Government Education Ethical Approval



Directorate: Research

meshack.kanzi@westerncape.gov.za
Tel: +27 021 467 2350
Fax: 086 590 2282
Private Bag x9114, Cape Town, 8000
wced.wcape.gov.za

REFERENCE: 16535DB3E00000C-20231116
ENQUIRIES: Mr M Kanzi

Ms Joricke van der Merwe
11 Darling Street
George
6529

Dear Joricke van der Merwe,

RESEARCH PROPOSAL: EXPLORING THE POTENTIAL OF MINDJOY AS AN ARTIFICIAL INTELLIGENCE TUTOR FOR SOCRATIC LEARNING AND FOSTERING 21ST-CENTURY SKILLS IN A GRADE 9 MATHEMATICS CLASS OF THE GENERAL EDUCATION CERTIFICATE.

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **1 December 2023 till 30 September 2024**.
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Mr M Kanzi at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

**The Director: Research Services
Western Cape Education Department
Private Bag X9114
CAPE TOWN
8000**

We wish you success in your research.

Kind regards,
Meshack Kanzi
Directorate: Research
rvshen2023

8.13 Appendix M: Mindjoy's Privacy Policy

- **Legal obligation:** In some cases, we may need to process your personal information in order to comply with an obligation imposed by law.

How We Use Your Information

More specifically, we may use your personal information for one or more of the following purposes:

- **Platform Maintenance:** Manage, maintain, and continuously improve our website and app, ensuring smooth operation and enhanced user experience.
- **User Access:** Manage user access to our website, app, and additional features, including the potential to restrict access when necessary.
- **User Experience:** Deliver a high-quality and customized learning experience, enhancing the overall value for users. This includes analyzing usage patterns and personalizing the user experience.
- **Communication:** Notify and communicate with users about updates, benefits, changes, technical notices, security alerts, support messages, and customer support inquiries related to our products and services.
- **Marketing and Engagement:** Market our services, including sending communications about our products, features, promotions, news, and events. Users can opt out of marketing communications as needed. Provide personalized advertising and marketing to enhance user engagement.
- **Account Management:** Assist users in managing their Mindjoy account, facilitating account settings changes, and processing payments for Mindjoy services.
- **Protection and Security:** Detect and prevent fraudulent or unauthorized use to ensure the security of our Service, as well as detect security incidents and protect against malicious or illegal activities.
- **Feedback and Testimonials:** Collect and potentially post testimonials from parents, students, and coaches to showcase the value of our services.
- **Strategic Improvement:** Use feedback and data to improve our educational, networking, marketing, social, and recruitment strategies.
- **Legal and Compliance:** Comply with legal obligations, respond to lawful requests, handle legal claims, and protect Mindjoy's rights and assets.
- **Business Activities:** In relation to business actions such as mergers, acquisitions, or sales, and ensuring the continuous provision of our services.
- **Safety:** Take necessary actions and precautions to ensure the safety of our users.

3. Information Sharing and Disclosure

We do not sell or rent your personal information to third parties. We may share your information in the following circumstances:

- **Service Providers:** We may share your information with third-party service providers that help us operate and maintain our Service, such as hosting providers and security services. These providers are required to protect your information and use it only for the purposes for which it was disclosed.

In order to open and operate an account for you, provide you with our products and services, or communicate with you, we collect information in the following categories:

- **Account Information:** When you create an account with Mindjoy, we collect your name, email address, contact number, password, and billing information. If you are an educator or administrator, we may also collect your role and the name of your educational institution.
- **Student Data:** We collect information about students provided by the educational institution, educators, or students themselves. This may include student names, grades, and school-related performance data. We collect only the minimum amount of information necessary to provide our Service.
- **User-generated Content:** When you interact with the Mindjoy Platform, we collect the questions you ask, the responses generated by the AI, and any feedback you provide.
- **Usage Data:** We collect information about how you interact with our Service, such as the features you use, the time you spend on the platform, and the device you use to access the Service.
- **Technical Data:** We collect technical data, such as cookies, your IP address, browser type, device information, and operating system, to improve our Service and ensure compatibility with various devices.
- **Communication Information:** If you communicate with us, we collect your name, contact information, and the contents of any messages you send.
- **Third-party integrations:** We allow you to connect third-party applications to our Service for the purposes of signing up for an account, signing in to an existing account, and importing classroom roster data. Signing up and signing in to our Service requires access to your email, first name and last name. Importing classroom roster data will require permission to access your classrooms, classroom rosters and student email addresses. Third-party applications include but are not limited to, Google Classroom and Microsoft Teams for Education. Access tokens obtained through integrations are stored in an encrypted format for enhanced security.
- **Publicly available information:** We may obtain Personal Information about you from other sources, including public records, publicly available information on internet sites, and third parties that help us update, expand, and analyze our records and inform our marketing and recruitment efforts. For instance, we may use information from LinkedIn or from a third-party data provider to update information about you in our contact database.

2. Processing your personal information

We will only collect, use, share or otherwise process your personal information where it is necessary for us to carry out our lawful business activities and subject to the data protection laws in your country or state. In doing so, we rely on one or more of the following lawful grounds for processing your personal data:

- **Contractual necessity:** We may process your personal information where it is necessary in order for us to provide our products and services to you or to otherwise comply with our obligations under Mindjoy Terms of use.
- **Consent:** In some cases, we will only process your personal information where you provide us with your express consent for such processing.

- **AI Models and technologies:** In order to provide the Service, we make use of AI models and technologies hosted by third parties. These third party systems receive chat messages in order to generate AI responses, classify information and provide moderation assessments. We do not share your personal information with third party AI providers, and do not make use of third party services that train Large Language Models (LLMs) on your data.
- **Legal Compliance:** We may disclose your information if required by law, such as in response to a subpoena, court order, or government request
- **Business Transfers:** If we are involved in a merger, acquisition, or sale of assets, your information may be transferred as part of that transaction.

4. Security of your Personal Information

Mindjoy places great importance on ensuring the security of your personal information. We regularly review and implement appropriate and reasonable technical and organisational security measures to keep your personal information safe. Employees of Mindjoy are trained to handle personal information securely and with the utmost respect, failing which they may be subject to disciplinary action. Although we take steps to secure your personal data, we cannot guarantee that your personal data will always remain secure and, in the event of a data breach, we refer you to the section below titled "Data breaches". Importantly, you are responsible for securing the login credentials for your Mindjoy account.

5. International Data Transfers

Mindjoy is a global organization, and during the course of providing our services, your data may be transferred, stored and processed in a region outside of the jurisdiction that you reside. As such, the laws of those countries may differ from the laws applicable within your own country. By accepting this Privacy Policy, and then submitting your personal information, you expressly consent to the transfer, storing or processing of such personal data outside of your jurisdiction.

6. Electronic marketing

We may send you information about our products, services, news and promotions, or otherwise communicate with you, by email, push or in-app notifications, text message or other means for marketing purposes. When we communicate with you for marketing purposes we will do so only in accordance with applicable law, including consent or opt-out rules.

You may always opt out of receiving marketing communications at a later stage by clicking on the "Unsubscribe" option included in every marketing communication sent to you and you can also manage your communications preferences via your account communications settings in our app or on our website.

Please note that unsubscribing from marketing content will not stop you from receiving important communications in relation to the security or operation of your Mindjoy account.

7. Compliance with Student Privacy Laws

We adhere to applicable federal student privacy laws, including the Family Educational Rights and Privacy Act (FERPA) and the Children's Online Privacy Protection Act (COPPA). We have implemented measures to ensure compliance with these laws, as outlined in our engineering specifications. If you believe we have not complied with these laws, please contact us at support@mindjoy.com.

8. California Privacy Rights

If you are a California resident, you have certain rights under the California Consumer Privacy Act (CCPA), including the right to access, delete, and opt-out of the sale of your personal information. Since we do not sell your personal information, the right to opt-out of the sale does not apply. To exercise your right to access or delete your personal information, please contact us at support@mindjoy.com.

9. EU / EEA and UK Data Subjects

If you are a data subject in the European Union (EU), European Economic Area (EEA), or the United Kingdom (UK), you have certain rights under the General Data Protection Regulation (GDPR) or UK GDPR, including the right to access, correct, delete, restrict the processing of, or object to the processing of your personal information. To exercise these rights, please contact us at support@mindjoy.com.

Additionally, if you are an EU / EEA or UK data subject, you have the right to lodge a complaint with your local data protection authority.

10. Age Restrictions

Our Service is intended for use by educational institutions, educators, and students. Mindjoy collects and uses student data at the direction of the school, and therefore relies upon the school to provide appropriate notice to parents of the school's usage of Mindjoy. Mindjoy does not knowingly collect any information from children under the age of 13 unless verifiable parental consent has been provided. If we become aware that we have collected personal information from a child under the age of 13 without verifiable parental consent, we will take steps to delete that information promptly. Contact support@mindjoy.com if you believe we have inadvertently collected this information so that we can delete it as soon as possible.

11. Additional matters related to your personal information

Data Retention and Deletion

We retain your personal information only for as long as necessary to fulfil its intended educational purpose. You may request the deletion of your account and personal information by contacting us at support@mindjoy.com. For students, parents or guardians may request the deletion of their child's personal information by contacting the student's educational institution or us directly.

Access and Control

Parents or guardians have the right to review their child's personal information collected by our Service, correct any inaccuracies, and request the deletion of information that violates privacy laws. To exercise these rights, please contact us at support@mindjoy.com or the student's educational institution.

Your Rights

Most of the data Mindjoy collects, and the ways in which we use it, are necessary for us to provide and improve the services we provide to you, or to comply with our obligations. In certain situations, we give you the ability to choose how we use your data. Depending on the country or state in which you live, you may have certain rights relating to your personal data, including the right to:

- ask us for a copy of the personal data we hold about you;
- ask to have your personal data transferred to you or to a third party chosen by you in a structured, commonly used and machine readable format;
- object to the processing of your personal data, including processing for marketing purposes;
- opt out of the sharing of your personal data with our affiliates or third parties (either for the specific purposes outlined in this policy or for the purpose of marketing their products and services to you); or
- ask that we correct, delete, or restrict the processing of your personal data.

Please contact us at support@mindjoy.com if you would like to exercise any of the above rights which you are entitled to exercise free from discrimination. These rights are limited in some situations and we may not be able to agree to your request. This could be because we have a legitimate reason for processing your personal information (for example where we have legal obligation to process your personal information, or it is in our legitimate interests to do so) or the right does not apply to the personal data we hold about you.

Data breaches

We will notify you and, where applicable, the relevant supervisory authority, of any data breach in accordance with local law.

Revisions to this Privacy Policy

We may amend this Privacy Policy from time to time. You should visit the website regularly to check when this Privacy Policy was last updated and to review the current Policy. We will do our best to notify you of any substantive amendments to the Privacy Policy and any such notice will be posted on our application or our website, or sent by email to the address associated with your Mindjoy Account.

Third-Party Links

Our Service may contain links to third-party websites, products, or services. We are not responsible for the privacy practices of these third parties, and we encourage you to review their privacy policies before providing them with your personal information.

Payment processors

In general, when you purchase classes from Mindjoy, your payment card information is provided directly to our third-party payment processor, Stripe, and Mindjoy Learning does not collect or store that information. However, we may receive limited information about your payment card from Stripe, such as the last four digits of your card, the country of issuance, and the expiration date.

Updates to Your Information

If you need to update or correct your personal information, please contact us at support@mindjoy.com or update it directly through your account settings.

By using our Service, you acknowledge and agree to the terms of this Privacy Policy. If you do not agree with any part of this Privacy Policy, you should not use our Service.

Contact Us

If you have any questions, concerns, or requests related to this Privacy Policy, please contact our Data Protection Officer at: support@mindjoy.com

8.14 Appendix N: Extraction of chat dialogue between researcher and CLAUDE.

Analyzing Learner-AI Tutor Dialogues for Qualitative Research ▾

Table 1: Analytical Tool for testing Mindjoy's Socratic Questioning ability	Table 2: Analytical Tool for testing Mindjoy's Socratic Questioning ability																																			
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Test Criteria	Description	Example																																		
Guiding Questions	Does the AI tutor guide the learner to explain and understand the problem and concepts through questioning?	Calculate the area of a circle with a diameter of 7 cm. "What do you need to calculate the radius of the circle?"																																		
Critical thinking skills	How effectively does the AI tutor use critical thinking as a tool for questioning?	Adding questions of purpose and then assessing the purpose. "What is the purpose of the calculation you just did?"																																		
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- Participants' perceptions of the potential co-intelligence roles that the Socratic Generative AI tutor may play in their learning.

8.15 Appendix O: Letter from the Principal stating permission from both SMT and SGB

--- Forwarded Message ---
From: gerrit ruddolph <gerritruddolph@yahoo.com>
To: GERRIT RUDOLPH <gerritruddolph@yahoo.com>
Sent: Thursday, February 8, 2024 at 12:34:21 PM GMT+2
Subject: Re: Permission to enter school premises for Master's thesis

Geagte me. J. van der Merwe

Hoop en vertrou dat dit baie goed gaan. Ek erken ontvangs van u e-pos en skrywe/versoek.

Ten einde u versoek aan die SBLS-dagbestuur, vir oorweging en goedkeuring voor te lê, verneem ons graag ten opsigte van die volgende, van u.

Na aanleiding van die korrektiewe maatreël wat tydens u Progressiewe Disiplinêre Vergadering op Vrydag 15 September 2023 teen u ingestel is, kan u asseblief inligting aan ons verskaf ten opsigte van Bestuursverwysing-sessies wat u deur die WKOD se "Employee Health and Wellness Program" bygewoon het.

Bale sterkte met die belangrike navorsing en studies. Verneem graag van u.

Die uwe

| Gerrit Jacobus Rudolph |
Hoërskool OUDTSHOORN High School
Principal
Cell: 082 964 0832
Tel: 044 279 1631/4

On Monday, February 5, 2024 at 09:50:08 PM GMT+2, Joricke Van Der Merwe <vmjor002@mjuct.ac.za> wrote:

Dear Mr Gerrit Rudolph and other senior management team members involved,

I am writing to request permission to conduct research at Oudtshoorn High School on Monday, 12th February 2024. Kindly find attached a letter of request as well as all ethical clearance from both UCT and the WCED for your perusal.

Yours in pursuit of wisdom,
Joricke