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University of the Western Cape Faculty of Education Book Series

Volume 1

Future-proofing STEAME education in South Africa

Edited by

Rajendran Govender, Josef de Beer, Rouaan Maarman & Rajendra Chetty

University of the Western Cape
Faculty of Education Book Series
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Cover image: The image on the cover is an artwork by a Grade 6 learner (in 2024), Annabel Ungerer, from Eikestad Primary School, Stellenbosch. This was an artwork submitted for an arts competition, where school learners were asked to express views on astronomy. The UWC's Science Learning Centre for Africa launched this competition for learners in the STEM field in 2023, and in partnership with NWU, IDIA, AfAS, the Iziko Museums of South Africa, SKAO and SARAO, sponsored the 2024 competition. More than 120 entries were received from all over Africa and Annabel's artwork was one that received positive feedback from the adjudicators. The artwork is printed with the permission of the artist.

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Rouaan Maarman & Rajendra Chetty**

AOSIS

Peer-review declaration

The publisher (AOSIS) endorses the South African 'National Scholarly Book Publishers Forum Best Practice for Peer-Review of Scholarly Books'. The book proposal form was evaluated by our Social Sciences, Humanities, Education and Business Management editorial board. The manuscript underwent an evaluation to compare the level of originality with other published works and was subjected to rigorous two-step peer review before publication by two technical expert reviewers who did not include the volume editor and were independent of the volume editor, with the identities of the reviewers not revealed to the volume editors or authors. The reviewers were independent of the publisher, editors and authors. The publisher shared feedback on the similarity report and the reviewers' inputs with the manuscript's editors or authors to improve the manuscript. Where the reviewers recommended revision and improvements, the editors or authors responded adequately to such recommendations. The reviewers commented positively on the scholarly merits of the manuscript and recommended that the book be published.

Research justification

This book aims to contribute to the discourse of finding innovative solutions to the myriad of challenges facing science education in South Africa. This book positions itself in the multi-disciplinary focus on Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education, rather than the traditional narrow focus on STEM. The chapters in the book explore the challenges and opportunities facing STEAME education in a complex 21st century and at the advent of a society with a strong artificial intelligence component in its DNA. The leitmotif of the book is how engaging pedagogies could be utilised in the classroom to enhance self-directed learning – a *sine qua non* to future-proof South Africa's science and technological advancement.

This is a book written by a scholar for scholars, and the target audience of the book includes academics and researchers in the field of science education and scholars engaged with innovative teaching pedagogies, particularly approaches that would enhance the achievement of learners in disadvantaged contexts.

The chapters in the book, although eclectic in approach, all contribute to the central theme of the book. Most of the chapters lean on textual analyses, literature reviews or concept papers, which disclose new ideas before full validation, but some chapters disseminate empirical data.

After the final chapters were submitted, the editors were responsible for reviewing the content and then providing feedback to the authors to make amendments. AOSIS then managed an independent and rigorous single-blind peer-review process.

In accordance with the Department of Higher Education and Training's guidelines, this book contains more than 50% original research content not published before, and no part of the book has been plagiarised. The following two chapters are based on the author's dissertations and published work, and the necessary acknowledgement is provided in the chapters: 'The wellness of STEAME teachers', by Rubina Setlhare, Ronél Koch and Mokgadi Moletsane and 'The infusion of arts and entrepreneurial thinking in STE(A)M(E) education: Opportunities and challenges', by Nigel Prinsloo, Colette February, Josef de Beer and Celia Booyse.

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Contents

Abbreviations and acronyms, figures and tables appearing in the text and notes

List of abbreviations

4IR	Fourth Industrial Revolution
ABE	Adult Basic Education
ACET	Adult and Community Education and Training
A & E	arts and entrepreneurship
AI	artificial intelligence
AIM	affect infusion model
AIoT	artificial intelligence of things
AR	augmented reality
ATP	annual teaching plans
BEd	Bachelor of Education
CAPS	Curriculum and Assessment Policy Statement
CETC	Community Education and Training
CHAT	cultural-historical activity theory
CLCs	community learning centres
COI	community of inquiry
CPTD	continuous professional teacher development
CL	cooperative learning
CT	critical thinking
CT	computational thinking
CTLI	Cape Teaching and Leadership Institute
DAIM	dialogical argumentation instructional model
DBE	Department of Basic Education
DoE	Department of Education
DHET	Department of Higher Education and Training
DST	Department of Science and Technology
EGRA	Early Grade Reading Assessment
ESDC	embodied, situated and distributed cognition
HE	higher education
HEI	higher educational institution
HOTS	higher-order thinking skills

IBL	inquiry-based learning
ICTs	information and communication technologies
IoITE	internet of intelligence of things in education
IoT	internet of things
IK	indigenous knowledge
IKS	indigenous knowledge systems
ISP	internet service provider
LMIC	low- to middle-income countries
HOS	history of science
MALGC	Master in Adult Learning and Global Change
MI	multiple intelligence
MM	mathematical modelling
MR	mixed reality
MTBBE	mother-tongue-based bilingual education
NCV	National Certificate Vocational
NECT	National Education Collaboration Trust
NFT	non-fungible token
NLP	natural language processing
NOIKS	nature of indigenous knowledge systems
NOS	nature of science
NSC	National Senior Certificate
NSTF	National Science and Technology Forum
OBE	outcome-based education
PALAR	participatory action learning and action research
PALC	public adult learning centres
PAR	participatory action research
PAT	performance assessment task
PBL	problem-based learning
PCK	pedagogical content knowledge
PD	professional development
PMT	pre-service mathematics teacher
PPC	person-process-context
PTD	professional teacher development
RNCS	Revised National Curriculum Statement
RPL	recognition of prior learning
SADTU	South African Democratic Teachers Union
SLCA	Science Learning Centre for Africa
SDG	Sustainable Development Goal

SDL	self-directed learning
SCP	Senior Curriculum Planners
SGB	school governing body
SKA	Square Kilometre Array
SMT	school management team
STEAME	Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship
STEM	Science, Technology, Engineering and Mathematics
SU	Stellenbosch University
TALIS	Teaching and Learning International Survey
TEAC	teaching English across the curriculum
TIA	Technology Innovation Agency
TLA	teaching, learning and assessment
TIMSS	Trends in Mathematics and Science Study
TVET	Technical Vocational Education and Training
VR	virtual reality
UCT	University of Cape Town
UWC	University of the Western Cape
WCED	Western Cape Education Department
WITA	Women in Tech Africa
WPPSET	White Paper on Post-School Education and Training
ZPD	zone of proximal development

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Zainoenisa Allie has a strong background in sciences, and she garnered recognition for exemplary teaching at national and international conferences, receiving awards for best poster and oral presentations. She is currently a lecturer at the School of Science and Mathematics Education and a part-time PhD student at the University of the Western Cape. She received the faculty's Emerging Lecturer Award of Excellence in Teaching and Learning in 2017. Her research focuses on identifying and addressing alternative misconceptions in science education and the role of alternative conceptions in conceptual understanding.

Preface

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This book is the result of a collaborative writing project in the Faculty of Education at the University of the Western Cape. It was a unique and rewarding journey where colleagues from different disciplines and with a wide repertoire of skills and knowledges worked together to address an interesting range of themes within the area of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education. Each chapter is a noteworthy contribution to teaching and learning in a more multi-disciplinary way that combines science, technology, engineering, arts, mathematics and entrepreneurship to guide new pedagogical approaches to student inquiry, discussion, problem-solving, self-directed learning, indigenous knowledge systems, etc. Although the STEAME education discourse already started in 2006, the past two decades did not ensure an established and robust body of research. Reasons for this shift towards STEAME education include arguments related to gender- and racial differences, skill sets developed by students and teacher professional development to pay justice to the STEAME agenda.

The book emerges three decades after the democratic dispensation of 1994 that heralded a transformation in education. While we continue to

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grapple with the legacies of the past, this book project has provided us an opportunity to review our scholarly engagement and embrace opportunities for the future. Our work in teacher education is committed to the development of a quality education system that enhances the achievement of all children regardless of race, class, gender, sexual orientation or ability. The authors of each chapter engage with pedagogies that enhance learning and emancipate the minds of children to enable the shift from a legacy of dysfunction to higher levels of scholastic achievement in STEAME education. While we take cognisance of the challenges the education system is facing at present, we foreground constructive recommendations for the amelioration of the present highly untenable situation, particularly in the area of science and mathematics education.

The diagnostic reports on the National Senior Certificate examinations repeatedly note the low achievement of learners in Mathematics, Physical Sciences, Life Sciences and languages. A very small percentage of learners respond appropriately to the cognitively demanding higher-order questions presented in the respective examinations, particularly questions that require critical and creative thinking. Given the current schooling climate of ineffective teaching and learning practices in the majority of schools, this book urges educators to expend more time on using appropriate and relevant pedagogical approaches that develop the understanding, reasoning and problem-solving capabilities of learners. Hence, this book provides suggestions, based on extensive and intensive literature study and textual analyses. A reflective practitioner approach is evident in the chapters with reflection-in-action, reflection-on-action and reflection-for-action. Themes covered include critical thinking; problem-based learning; problem-solving, mathematical modelling; engaging pedagogies for self-directed learning; affordances of change laboratories for systematic change; and affordances of coding and robotics to augment and support teaching and learning. In addition, this book provides an exposition of nascent research on the affordances of indigenous knowledge to contextualise the science and mathematics Curriculum and Assessment Policy Statement (CAPS) themes for culturally diverse learners in South Africa as well as the meaningful use of information and communication technologies (ICTs) in supporting STEAME education.

The learning environment, which fosters self-directed learning, should promote practices where learners take responsibility for their own learning and critical thinking and give students the chance to assess concepts, make defensible arguments, pose questions, and imagine and explain phenomena. All mathematics or science or technology students who engage in self-directed learning are required to think critically about their learning objectives, learner characteristics, curriculum and learning, teaching, and evaluation processes from an entirely new angle. By experimenting with different approaches to solve mathematical or science or technology issues, students who engage in self-directed learning develop their creativity and sharpen their critical thinking abilities.

Problem-based learning (PBL) is a learning approach that allows learners to do research, integrate theory and practice, and apply knowledge and skills to develop a solution to the defined problem. The key elements of PBL include (1) providing an unresolved, structured problem that will require thoughts or consideration about cause and solution; (2) utilising learner-centred methods, by means of which learners ascertain requirements for learning; (3) teachers acting as facilitators giving guidance and (4) solving authentic problems that reflect the professional practice. If we want students to deal effectively with problems taken from real-world situations, we must engage students in tasks that allow them to search their 'toolbox' in a cooperative learning context to access and invoke necessary knowledge and experiences.

The book encourages radical and innovative ways of teaching and learning, to change traditional habits and approaches to teaching the STEAME subjects that ensure meaningful learning will be promoted and sustained. This will invariably enable both teacher education students and learners to develop the necessary knowledge, competencies and skills that will make it possible for them to become functional and employable citizens for the world work defined by new technologies and the affordances of artificial intelligence.

We are hopeful that this contribution to STEAME education and the exciting world of teacher education will be an inspiration to all the readers.

Acknowledgements

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Chapter 1

Science education in South Africa: Possibilities and challenges

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Abstract

When considering science education, the focus of research is often limited to the schooling sector and higher education institutions' role in teacher professional development. In order to future-proof Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education, it is important to broaden our focus to include the post-school sector and, more importantly, the Technical Vocational Education and Training (TVET) and Adult and Community Education and Training (ACET) sector. This chapter has such a holistic focus. Cultural-historical activity theory (CHAT) is utilised as a lens to interrogate science education in South Africa. The chapter highlights the socio-economic inequality that characterises education in South Africa, despite 30 years of democracy, and how this leads to underachievement. It also sheds light on the schism between the intended and the enacted curriculum.

Introduction

South Africa showcases cutting-edge technology such as the Square Kilometre Array (SKA) in the Northern Cape province. This is arguably the most advanced radio astronomy project in the world (Walker 2019) and illustrates South Africa's scientific and engineering competitiveness. The question arises whether we grow our own timber and whether we are future-proofing the provision of a next generation of scientists, engineers and artisans. Does the schooling system, higher education institutions (HEIs) and Technical Vocational Education and Training (TVET) colleges succeed in this future-proofing? Will South Africa be able to remain competitive in the international science arena? South African school learners perform poorly in international benchmark tests such as the Trends in Mathematics and Science Study (TIMSS). In TIMSS 2019, only 37% of Grade 5 South African learners reached the low benchmark in Mathematics, which is a big concern. Only 1% of South African Grade 5 learners reached the advanced benchmark (Gondwe & Wills 2022). South Africa lags behind numerous other countries: out of the 64 participating countries in TIMSS 2019, South Africa only outperformed Pakistan and the Philippines (Gondwe 2019). Tomlinson (2023) states:

> Let us call it what it is. The South African education system is in ruins. Centuries of colonisation and apartheid ensured this ruination. And I would contend that a singular lack of imagination and vision since 1994 has ensured we have remained mostly stagnant. (p. 3)

For example, as shown in Table 1.1, the overall percentage achieved at 40% and above in Mathematics over the past five years (2018–2022) was consistently below 38%.

TABLE 1.1: Overall achievement rates in Mathematics (Department of Basic Education [DBE] 2022).

Year	No. wrote	No. achieved at 30% and above	% achieved at 30% and above	No. achieved at 40% and above	% achieved at 40% and above
2018	233,858	135,638	58.0	8,674	37.1
2019	222,034	121,179	54.6	7,751	35.0
2020	233,315	125,526	53.8	8,264	35.6
2021	259,143	149,177	57.6	9,761	37.6
2022	269,734	148,346	55.0	9,741	36.0

Source: DBE 2022, National Senior Certificate Diagnostic Report 2022 – Part 1 Content Subjects, p. 197, graph 10.1.2.
Key: No., number; %, percentage.

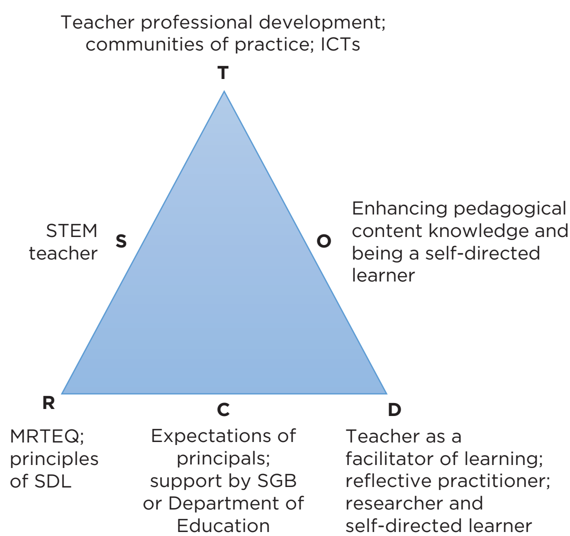
Gondwe (2019) highlights a number of important lessons and considerations from the TIMSS 2019 study. Firstly, we need to recognise the inequality among schools, and that socio-economic status replaced race as a major factor in determining school culture and environment (Shepherd 2011). It is often historically black schools that serve the economically disadvantaged learners, whereas children of more affluent parents benefit from better-resourced and high-quality schools (Gondwe 2019). Inequalities in educational achievement are often a product of income, with more affluent learners outperforming their poorer counterparts (Shepherd 2011). Looking at science education in South Africa therefore needs a refined lens, which will acknowledge all the variables and nuances in the sector. For this reason, cultural-historical activity theory (CHAT) will be used as a research lens in several sections of this book.

This scholarly work also highlights the need for more holistic approaches to science education. The STEAM education discourse, advocating for the infusion of arts (represented by the letter 'A'), started as early as 2006, yet the past two decades' discourse did not result in an established and robust body of research (Marín-Marín et al. 2021), or even agreement among science educators for its inclusion. Arguments for the inclusion of the arts in science education include gender and racial differences, and skill sets developed by students through such holistic approaches (Marín-Marín et al. 2021). Also, the digital society in which we live demands an increased focus on the use of technological media and tools. However, arguments against the infusion of arts in science education include epistemological and ontological considerations, for example, that science education should build on the tenets of science. Lately, there have been various permutations of Science, Technology, Engineering, Mathematics (STEM)/STEAM, for example, STEAME, with the second 'E' representing entrepreneurship (Venturelab n.d.), or STREAM, with the 'R' representing either robotics or reading. This conundrum is addressed in the various chapters of the book, but for consistency, STEAME will be used.

The use of cultural-historical activity theory as a research lens in this book

Cultural-historical activity theory has its roots in social constructivism and is embedded in the theories of Vygotsky (1978). Cultural-historical activity theory assists in interpreting data embedded in specific cultural and historical contexts. The current state of South African education should be seen in the context of the Apartheid history of the country and the socio-economic inequality that still exists in a post-apartheid society. Cultural-historical activity theory provides a flexible meta-theoretical framework to provide insight into the nuances of science education in the country (Mentz & De Beer 2019).

Cultural-historical activity theory utilises an activity system as the unit of analysis (Mentz & De Beer 2019) – see Figure 1.1. An activity system could be a STEAME classroom or an entire sector. In an activity system, there is an acting Subject (S) working towards the realisation of an Object (O). For achieving the object, Tools (T) are utilised (which could include language, pedagogies or resources). Rules (R) dictates the activity (it could be the curriculum, guidelines or policies). The Community (C) consists of all the stakeholders in the activity system (e.g. the teacher, learners, parents and school governing body), and the Division of Labour (D) refers to the



Source: Based on Engeström (1987). Authors' own diagram and interpretation.
Key: ICTs, information and communication technologies; T, tools; STEM, Science, Technology, Engineering, Mathematics; S, subject; O, object/objective; R, rules; MRTEQ, Minimum Requirements for Teacher Education Qualifications; SDL, self-directed learning; C, community; SGB, school governing body; D, division of labour.

FIGURE 1.1: The use of cultural-historical activity theory as a research lens: Clarifying terminology related to the activity system.

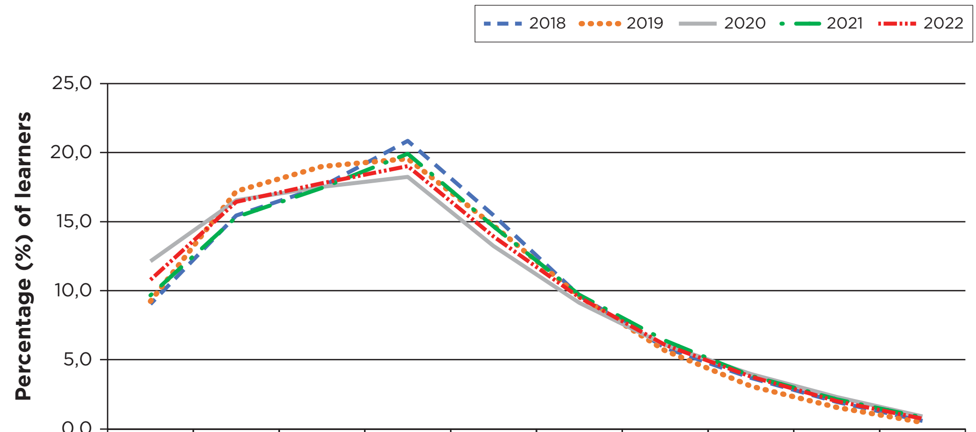
different roles of the stakeholders, especially the Subject. If the subject is a teacher, such division of labour would refer to the different roles of the teacher, for example, the teacher as a reflective practitioner, the teacher as a facilitator of learning, the teacher as an assessor or the teacher as an agent of change.

The object could be, what activity theorist Engeström (2008) calls, a 'runaway object', which refers to complex activity systems characterised by contradictions and tensions. Science education is such a complex activity system, the 'runaway object' being the fact that quality and efficiency seem to be evasive and rare. Despite 30 years of curriculum transformation, and big financial investment in science education/teacher professional development (PD), the object (excellence in STEAME education) is still 'on the run'. In several chapters of this book, CHAT will be used to shed light on the contradictions/tensions that lead to such a 'runaway object' and how this could be addressed or improved.

It is important to note that CHAT could be used on three different levels (Rogoff 1995), namely:

- On the personal plane, where the subject is a person (i.e. a learner or a teacher)
- On the interpersonal pane, more than one subject is present, and the focus is on the interplay between the two subjects (e.g. the teacher [teaching activities] and the learner [learning activities])
- On the institutional plane, the focus is on a phenomenon/construct, and not a person (e.g. the subject could be science education or self-directed learning [SDL]).

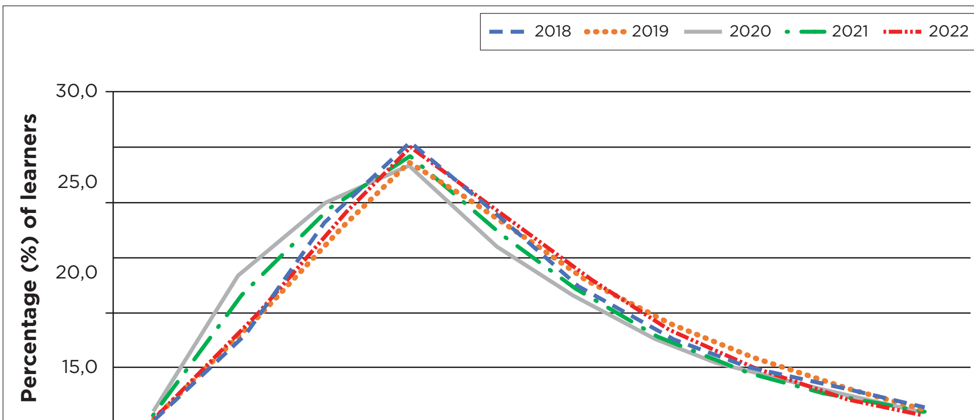
The teaching and learning of science, technology and mathematics in South African schools are not yielding the intended outcomes of South Africa's education policies and curricula as evident in the performance of our learners in the high-stakes National Senior Certificate (NSC) examinations and international assessments such as TIMSS. The major concern in the NSC examinations is the small number of learners scoring beyond 60% in key gateway subjects such as Mathematics, Physical Sciences and Life Sciences (DBE 2022). For example, Figure 1.2, Figure 1.3 and Figure 1.4 extracted from the *NSC Diagnostic Report 2022 – Part 1 Content Subjects* (DBE 2022) show a very low number of learners responding appropriately and correctly to high-order questions, which are cognitively demanding and require reasoning, justification, argumentation, problem-solving, critical thinking, creative and innovative thinking. It suggests that our learning and teaching activities including formative and summative assessment tasks do not provide necessary and sufficient opportunities for our learners to engage in higher-order thinking tasks that are nested within the triad of problem-solving, critical thinking and creative thinking.



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2018	9,0	15,4	17,5	20,9	15,5	9,6	5,9	3,7	1,9	0,6
2019	9,2	17,2	19,0	19,6	14,7	9,6	5,6	3,1	1,5	0,4
2020	12,1	16,5	17,5	18,2	13,2	9,1	6,1	3,9	2,3	0,9
2021	9,7	15,3	17,4	19,9	14,7	9,7	6,4	3,8	2,1	0,8
2022	10,8	16,4	17,8	19,0	13,9	9,5	6,1	3,8	2,0	0,7

Source: DBE 2022, *National Senior Certificate Diagnostic Report 2022 – Part 1 Content Subjects*, p. 221, graph 11.1.2.

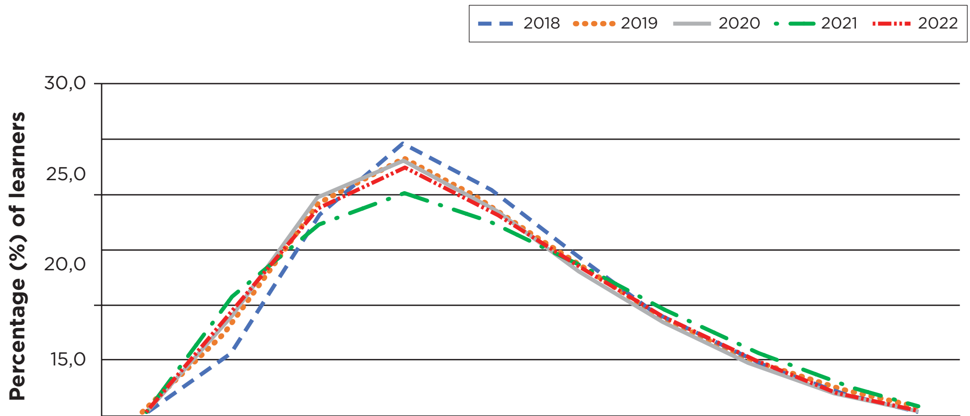
FIGURE 1.2: Performance distribution curves in Mathematics (percentage).



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2018	0,2	7,4	18,2	25,5	18,9	12,2	7,9	5,0	3,3	1,4
2019	0,3	8,0	16,1	23,8	18,6	13,3	9,1	6,0	3,4	1,3
2020	0,8	13,5	19,8	23,4	16,1	11,0	7,2	4,5	2,6	1,0
2021	0,6	11,2	19,2	24,2	17,4	11,9	7,5	4,4	2,4	0,9
2022	0,3	8,1	17,0	24,9	19,3	13,6	8,6	5,0	2,4	0,7

Source: DBE 2022, *National Senior Certificate Diagnostic Report 2022 – Part 1 Content Subjects*, p. 161, graph 8.1.2.

FIGURE 1.3: Performance distribution curves in Physical Sciences (percentage).



	0–9.9	10–19.9	20–29.9	30–39.9	40–49.9	50–59.9	60–69.9	70–79.9	80–89.9	90–100
2018	0,1	5,6	18,0	24,6	20,6	14,6	9,0	5,1	2,1	0,3
2019	0,2	8,2	19,2	23,3	19,1	13,4	8,6	5,1	2,4	0,4
2020	0,3	8,9	19,7	23,1	19,0	13,3	8,4	4,9	2,0	0,3
2021	0,6	10,7	17,2	20,2	17,6	14,0	9,8	6,0	3,0	0,7
2022	0,3	9,5	18,7	22,5	18,6	13,7	9,0	5,2	2,2	0,3

Source: DBE 2022, *National Senior Certificate Diagnostic Report 2022 – Part 1 Content Subjects*, p. 197, graph 10.1.2.

FIGURE 1.4: Performance distribution curves in Life Sciences (percentage).

To push the sections of the graphs shown in Figure 1.2 to Figure 1.4 higher up for the respective performance distribution in the interval 60% to 100% and break the cycles of continuous poor performance in Mathematics, Physical Sciences and Life Sciences, it is imperative that we rethink our learning and teaching practices, which permeates our classrooms across the majority of our schools in South Africa. In doing so, we must encourage the use of engaging pedagogies, which invoke problem-based learning; experimentation, investigations and project-based work; co-operative learning; and SDL.

Technical Vocational Education and Training, Adult and Community Education and Training, and Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship: A different perspective

In this section, our attention will be shifting to science, engineering and mathematics education in public TVET and Adult and Community Education and Training (ACET) institutions specifically.

This section will begin by investigating the historical contexts and policies that shaped the often under-resourced ACET and TVET sectors. The focus will then move to discuss how these historical legacies impacted the current trajectories of these institutions and how they are delivering on their mandates to develop and train often out-of-work youth and adults with the necessary knowledge and skills for work and self-employment. Finally, our attention will then shift to lecturer training programmes that have been developed post the White Paper on Post-School Education and Training (WPPSET) (2013) in an attempt to address un/underqualified TVET and ACET lecturers. A review of extant literature through the lens of CHAT considers issues affecting Community Education and Training (CETC) and TVET colleges, lecturers and students.

The section concludes by arguing that in order for our education system to be future-proofed, there needs to be increased cooperation and synergies between schools and ACET and TVET colleges as well as an increased focus on lecturer training and support. By seamlessly developing pathways between these institutions, our students will be better positioned to use lifelong learning in preparation for a rapidly changing world.

Expanding the focus of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship into the post-school sector

Adult and Community Education and Training and TVET in South Africa have historically been on the periphery of mainstream schooling policy and scholarship debates. Technical colleges provided the bulk of white artisan training in the apartheid era together with the support from parastatals. With the advent of democracy, there was the continued need for all races to have access to these training opportunities and TVET colleges were seen as the vehicle to achieve this. With the need to develop the sector as a viable alternative to universities and with the urgent need to address skills development and youth unemployment, resources were made available to colleges (Department of Education [DoE] 2006; Gewer 2010). However, though this did go some way to addressing the lack of resources at the time, this was not sustainable. For the adult education sector, the outlook was even worse. Arising out of the public night school system, chronic under-resourcing meant that these colleges were unable to develop into the strong well-resourced innovative institutions that they had envisaged (Aitchison 2003). In addition to the resource constraints, the TVET and ACET curricula have over time become chronically outdated with an underpinning neo-behaviourist and technicist approach to the achievement of specific outcomes based on industry standards and the school curriculum.

Historical perspectives of Technical Vocational Education and Training and Adult and Community Education and Training in engineering and mathematics

To understand the current context of STEAME in both the TVET and ACET sectors, it is important to understand their historical roots. Both institutions were born out of the need to provide alternative pathways for citizens to complete basic and technical education. In the old technical colleges, this was to address the ‘poor white’ problem but as the economy grew post the great depression. Vocational education and training was used in colonial and apartheid times to enforce racial segregation. Under apartheid, technical and vocational education and training was exclusively reserved for white people, coupled with job reservation (e.g. black African people were not allowed to obtain a mining blasting licence, which was a prerequisite for management positions). As opposition to apartheid increased, vocational training was opened to black Africans, but only in the 1980s, at the same time as apprenticeship and artisan training declined (Akoojee 2009; Kraak 2004). However, access to promotion to qualified non-white artisans was curtailed by the *Job Reservation Act* (1926) and subsequent apartheid legislation. Adult and Community Education and Training was initially offered as a means for adults to complete their schooling qualification. Successful night schools (e.g. St Francis) offered school qualifications and were a major source of ensuring black Africans obtained a matric qualification recognised by universities as opposed to racially segregated schooling not recognised as entrance to university. Then, after 1994, the emphasis shifted towards literacy and citizenry.

Technical Vocational Education and Training

Historically, STEAME subjects at TVET colleges (previously technical colleges) were mainly focused on Nated 191 (National Technical Education Report 191) Engineering Programmes. These programmes were introduced in the apartheid era and included areas such as automotive, construction and electrical engineering courses from levels N1 to N6. An N6 qualification was recognised as a two-year post-secondary schooling qualification. These legacy courses focused on the development of artisans where the college provided theory (over a trimester) and practical experience was provided in the workplace. Each level from N1 to N3 and N4 to N6 would take 18 months, respectively, to complete. These were part qualifications. An N6 qualification was recognised as a two-year post-secondary qualification. In recognition of the obsolete Nated qualifications, this new set of qualifications was introduced in 2007. These qualifications were theory-based courses and were completed over three years at Grades 10 to 12 levels of the formal schooling system.

The Nated courses were to be superseded by the National Certificate Vocational (NCV) courses. This, however, did not happen and the two programmes run concurrently. The Nated courses were preserved as a result of the outcry from business and industry who did not understand or recognise the NCV programmes. These courses from NCV1 to 4 combined both theory and practice and were completed over a year. However, the practical component of the NCV programme was not as extensive as initially envisaged. Students who completed NCV Level 4 would achieve the equivalent of a technical Grade 12. The NCV qualifications route provided access opportunities to universities, but this qualification is poorly understood by universities, and university access by NCV graduates has been minimal to date. All NCV qualifications have the same fundamentals, including Mathematics.

Since 1998, the *Skills Development Act* ensured that workplace and occupational training was conducted by private providers, and public TVET Colleges were increasingly relegated to providing theoretical training. This was only reversed after 2103. Therefore, skills and occupational programmes are also offered. These courses focused on basic plumbing and bricklaying. Lecturers at the colleges are either school teachers, qualified artisans or trainers from the corporate sector. However, the new qualifications framework for TVET College lecturers calls for vocational qualifications, teaching degrees and years of work experience.

Adult and Community Education and Training

In the public sphere, the focus of ACET is located in CETC colleges. In terms of STEAME subjects, the curriculum focus here has predominantly been in the form of Mathematics, Mathematical Literacy and at Adult Basic Education (ABE) Level 1 to 4 syllabus and Mathematics and Natural Sciences at Grade 12 (Aitchison 2003). The curriculum was school based and can be traced back to the early night school programmes where adults were offered the opportunity to complete their Grade 12 on a part-time basis. As the night schools mandate was expanded to offer literacy and numeracy at lower levels, these institutions went through various iterations from public adult learning centres (PALCs) to community learning centres (CLCs) to the current form of CETCs. Most of the lecturers teaching at the CETC colleges were school teachers. However, a new suite of ACET lecturer qualifications has been approved and is currently being rolled out at HEIs, which ACET lecturers need to obtain from 2015. The policy framework for qualifications in higher education for adult education and training educators and community education and training college lecturers was drafted in 2014 (Department of Higher Education and Training [DHET] 2014).

Current policy trajectories and implementation challenges in post-school education and training

Underpinning both ACET and TVET trajectories are the provisions offered in the WPPSET and subsequent amendments to the related legislation. The targets in the WPPSET 2013 are 2.5 million in TVET by 2030 and 1 million in ACET by 2030. These were later drastically reduced by the Treasury, which predicts 1.25 million in TVET by 2030. One of the key provisos of this policy is the need to expand provision to 1 million students and address the skills shortage in South Africa. The WPPSET also highlighted the need to ensure that the ACET and TVET curricula are able to address the competencies needed for the 21st century. However, though mentioned in the policy and some course outcomes, the competencies implemented have mainly focused on the occupational competencies in TVET and learning area outcomes in ACET (Aitchison 2004; Akoojee 2009). Broader conceptions of these so-called 21st-century competencies such as critical thinking, problem-solving and collaboration are only applied when they need to be assessed. Creativity or creative problem-solving is lacking at some institutions unless it is incorporated into the more creative courses (Daugherty 2013). Scholars have also been very critical of the skills and competencies that have been emphasised in TVET and CETC colleges (Allais 2012; Aitchison 2004). We will consider two developments affecting PSET and TVET in particular, namely, the Fourth Industrial Revolution (4IR) and the 21st-century competencies.

The Fourth Industrial Revolution

A key development challenge in the manufacturing and engineering trades is what is referred to as the 4IR. This era is characterised by digitisation, collaboration, automation, adaption and human–machine interaction (Bayode, Der Poll & Ramphal 2019). The change in the means of production that South Africa has experienced is having an impact on the nature and future of work, particularly for the artisan. Papier and Vollenhoven (2017) argue that traditional trades are in danger as technology and new materials replace older production processes. This, in turn, results in the need for new methods of training as well as new competencies among workers.

These shifting workplace competence requirements will consequently change the requirements for TVET and CETC students as the introduction of new technologies will require reform of the curriculum and assessment standards (Akoojee 2009). Over and above the increasing requirements for occupational competencies, there is also the need to ensure that artisans develop critical competencies such as problem-solving and critical thinking, as well as being able to use digital technologies and social media.

21st-century learning skills

There is increasing scholarship on the introduction of new technologies into the workplace that may result in some current jobs becoming redundant while at the same time requiring workers who remain to be retrained (Papier 2021).

Finegold and Notabartolo (2010) expanded on these 21st-century skills by identifying 15 general competencies in five categories. These are analytic skills, interpersonal skills, ability to execute, information processing and capacity for change and learning. The authors argue that while all five categories could be seen as important, there is little evidence of a relationship between these competencies and individual and organisational outcomes. Although Finegold and Notabartolo's model tends to focus on service occupations, it offers insights into competencies that form the basis of engineering and mathematics in the Nated and NCV courses currently offered at colleges. However, with the dominant focus on occupational competencies, there is little emphasis on creative competencies such as the arts as a means to broaden the skills in these STEAME subject areas.

Teacher education in Technical Vocational Education and Training and Adult and Community Education and Training

To address the increasingly complex and competing demands of work and community, ACET and TVET lecturer education programmes need to find innovative ways to address the needs of industry and the community. This includes the need to develop entrepreneurship skills in students who will be entering an economy where formal employment, particularly for youth, is declining. Papier (2012) highlights the complexity of the task for college lecturers whereby they must have disciplinary knowledge, practical skills and workplace experience.

In order to ensure the development objectives of the ACET and TVET curricula, there is a need for training of ACET and TVET lecturers in the field. New qualifications have been developed to facilitate this process. The University of the Western Cape (UWC) was one of the first universities in South Africa to offer the Post Graduate Diploma in TVET and is finalising new qualifications, building up to a PhD in TVET. The same process is evident in the ACET sector where UWC for many years has been offering an international programme – Master in Adult Learning and Global Change

(MALGC). Just recently, an Advanced Diploma in ACET has been approved at UWC.

However, though TVET and ACET lecturers have been encouraged to obtain the requisite qualifications, and limited bursaries have been sourced, this has not translated into improved remuneration let alone working conditions. Lack of resources, funding and onerous administrative burdens and an overloaded syllabus have all led to a high turnover of staff. In addition, as these qualifications in ACET and TVET are very specific to the institutions they serve, teachers have to do additional courses to become TVET and ACET lecturers and vice-versa. This leads to extra time and cost which can be a disincentive to them and the loss of expertise in the post-school sector. In addition, the qualifications of TVET College lecturers and ACET lecturers are not interchangeable.

Connecting pathways between schools, Technical Vocational Education and Training and Adult and Community Education and Training colleges

Both the National Development Plan and the White Paper on PSET highlight the need for synergies between the 'silos' of general and post-school education. However, access to higher education is difficult or virtually impossible based on the requirements imposed on access to institutions of higher learning (Needham 2019). These requirements place students from TVET and ACET colleges at a distinct disadvantage as in most cases they have to do a recognition of prior learning (RPL) programme in order to access a course for which they have studied (Aploon-Zokufa 2022).

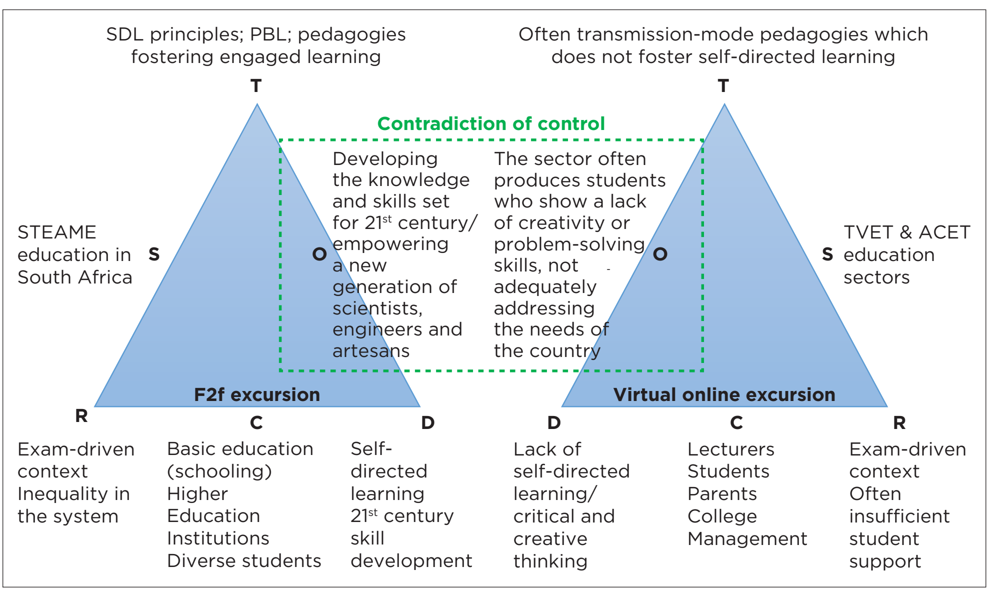
However, recent developments in schooling, that is, the three-stream model (DBE 2022), have highlighted both increasing differentiation and stratification in the South African education and training system. This presents both a challenge and an opportunity for implementing the arts and entrepreneurship in the curriculum.

Applying cultural-historical activity theory in Technical Vocational Education and Training and Adult and Community Education and Training

Cultural-historical activity theory is particularly useful in capturing the roles of the different actors/contexts involved in TVET/CETC colleges and workplace/community. Abdullah and Ziden (2013) argue that CHAT helps to provide a useful framework for improving the TVET system for the

21st century. They argue that diverse activities could be done where these activities involve multiple interconnections which will lead to meaningful and skilful manipulation of knowledge and skills. This is especially important in the intersection between the TVET college and the workplace. This is because vocational college students also struggle to link their knowledge gained through workplace experience to the requirements of the qualification. Naudé (2016), through focusing on the RPL in TVET colleges, looked at the academic institution and workplace or community using the components of the activity system to generate new knowledge and described disciplinary knowledge with strong rules and boundaries. These disciplines, especially in the occupational space, are strongly coded within a community of practice and do not allow the less-informed access to this knowledge. The workplace and community, forming another activity system, can be analysed in a similar manner but in a different context.

In Figure 1.5, CHAT is used on an institutional plane (Rogoff 1995), and two activity systems are juxtaposed. On the left, STEAME education (encompassing the schooling sector, post-school education and HEIs) is shown. The activity system on the right is the TVET and ACET sectors, and how these sectors contribute to the needs of the country in terms of



Source: Based on Engeström (1987). Authors' own diagram and interpretation which was adapted from Engeström (1987).
Key: T, tools; SDL, self-directed learning; PBL, problem-based learning; STEAME, Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship; S, subject; O, object/objective; TVET, Technical Vocational Education and Training; ACET, Adult and Community Education and Training; F2f, face-to-face; R, rules; C, community; D, division of labour.

FIGURE 1.5: A cultural-historical activity theory's focus on how Technical Vocational Education and Training and Community Education and Training colleges contribute to meeting national needs in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education.

science and engineering. There are several tensions that lead to a 'contradiction of control' (McNeil 2013) in terms of the shared objects of the two activity systems. As explained above, lecturers (part of the community [C] in the activity system) are often not well trained in terms of pedagogical content knowledge. The often-poor working conditions (e.g. poor remuneration and administrative burdens) lead to a high turnover of lecturers, which negatively impacts the teaching and learning project. TVET and ACET colleges often do not provide sufficient student support. The overloaded curricula often favour transmission mode teaching, at the expense of developing SDL in students.

The intended versus the enacted curriculum

In the new technological era in which we live, teachers face challenges in implementing the prescribed and intended (Sciences, Mathematics, Technology) curricula in schools. Challenges include how to engage learners for effective learning, how to teach complex and controversial topics and adopt appropriate teaching strategies and methods to accommodate various learning styles, how to address diverse learner abilities and skills in one classroom, time management and assessment of or for learning.

One of the greatest challenges is the decreasing learner numbers in school, as well as declining student numbers in higher education that opt to pursue science and mathematics disciplines as careers. As mentioned earlier in this chapter, struggles with relevant and up-to-date resources, especially in under-resourced schools, in the context of the inequality in the education system, also negatively impact the quality of STEAME education in South Africa.

Transformation of education in South Africa followed the pattern 'from OBE to C2005 to the RNCS' (Pudi 2006). After the 1994 elections/democracy, a new curriculum was adopted from countries such as the United States of America and Australia known as outcome-based education (OBE). The South Africa C2005 implemented in 1997 was based on the principles of OBE, and C2005 was seen as an introduction to OBE (DoE 2002). After the failure of successfully implementing C2005, a careful review of OBE in 2000 led to the construction of the Revised National Curriculum Statement (RNCS) that was implemented in 2001.[11] The RNCS was reviewed in 2009 followed by a staggered implementation of the curriculum-as-plan as per Curriculum and Assessment Policy Statement

11. Curriculum Changes In South Africa Since 1994 Timeline PDF – southafricanza.com

(CAPS) in 2012 (Grades 1–3 and 10), 2013 (Grades 4–9 and 11) and finally 2014 (Grade 12).

According to Crouch and Hoadley (2018), some of these changes were successful in the sense that they were put into action and had some of the intended effects, such as an improvement in the equality of resource allocation, but in instances such as changing the curricula, immediate outcomes were elusive. They believe that although there are positive signs, the transformations have not yet had the anticipated effect on average attainment or equality.

We could build on these signs of hope as we envisage a new curriculum to address the needs of the 21st-century learner, which addresses the preparation of informed citizens and employees of a technological era (Sustainable Development Goal [SDG] 4). In our context as student teacher educators, the metonymic doubling has meaning in the tensions experienced between the CAPS and the curriculum-as-lived (real-life situations and experiences). Thus, the question arises as to how we implement the CAPS so that it becomes a lived curriculum – a curriculum experienced by educators and students as a positive learning opportunity. In other words, how do we change the planned curriculum into a curriculum of experience?

Ted Aoki is known for his contributions to the varied aspects of the lived curriculum and pedagogy. Although he was not a productive publisher, his works have had a profound impact on the field of curriculum. A collection of his work has been compiled in a book named *Curriculum in a new key: The collected works of Ted Aoki*, edited by Pinar and Irwin (2004). According to these scholars, the difference between the two curricular worlds, that of the intended curricular programme and the enacted/lived curriculum, is emphasised by Aoki (Pinar & Irwin 2004). The curricular programme is what is commonly referred to as the curriculum. It is a plan that describes the learning that is anticipated of the students and provides the indicators for the process as well as the assessment criteria for achieving the learning. The lived curriculum refers to a pedagogical approach of how the curriculum is experienced or lived.

The curricular (intended) programme is a vision of the study programme/schedule that includes the objectives and content knowledge that learners/students should have achieved. The curricular programme thus represents the agents interested in providing teachers/educators with a vision of what they believe should be included in classroom instruction (Clandinin & Connelly 1992; Olson 2000).

The canonical curriculum question *What knowledge is of most worth?*, posed by Herbert Spencer in the 19th century (Broudy 1982), is often asked leading to sub-questions such as what knowledge, and pedagogy (strategies/methods/approaches), is of most worth for the new age, 21st-century students preparing for careers in science, mathematics and technology that is probably not known yet. But who is this new age citizen, the new generation Gen Z going on to Gen Alpha?

Becoming an employee in this technological era known as the 4IR begs an understanding of how the world of technology operates (Botha 2020). Johnson (in Eiser, Mayet & Johnson 2019) makes it clear in his alarming statement that education in pre-school through to postgraduate education needs to be reimagined. Therefore, educators have a challenging job in upskilling and/or re-skilling (Butler-Adam 2018) the students of tomorrow which poses implications for teaching, learning and assessment (TLA). More importantly, the quest for curriculum re-design focuses on how educators should promote relevant TLA not only in higher (tertiary) education but also in school (primary and secondary) education as well.

Technology is obviously a defining factor for the Gen Z and the upcoming Gen alpha characteristics, making the 4IR a reality in modern teaching and learning approaches. Because they are the first generations born in the 21st century, they might just be the most (technological) influential generation of the 21st century. Digital devices such as smartphones, tablets, iPhones, iPads and phone applications are introduced to this generation from a young age, and they use them as natural instruments for both entertainment and learning (Fourtané 2018; McCrindle 2014). Artificial intelligence (AI) is finding its way into education communities[12] and subjects such as Coding and Robotics is presented in the school curriculum (Govender 2023). According to its Annual Performance Plan 2022/2023, the DBE[13] intends to add Coding and Robotics as a subject. Beginning in 2023, these courses were scheduled to be piloted in some high school classes after being tested in primary school grades. Harvey (2017) echoes the voices of many educators in asking how our young people of today will be prepared for *this* future. The way forward lies in 'technologically informed pedagogical practices' (Waghid, Waghid & Waghid 2019, p. 4) resulting in informed, responsible and lifelong learners who would/could improve their technological knowledge and skill sets in preparation for the demands of 4IR and the curriculum for the 21st century. The debate on the tensioned spaces between the intended curriculum and the lived/enacted curriculum remains. If not addressed efficiently, this tensioned space could create a greater divide in educational communities.

12. See https://edtechmagazine.com/k12/article/ai-in-education-new-guidance-from-department-of-education-perfcon. Accessed 12 August 2023.

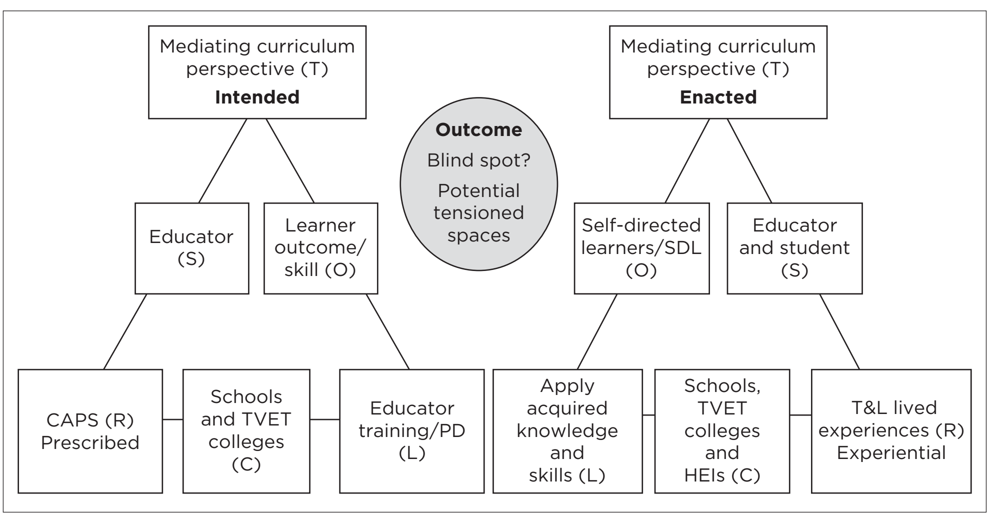
13. See https://www.education.gov.za/CodingCurriculum010419.aspx. Accessed 12 August 2023.

According to UNESCO, AI could play a role in addressing 'inequalities regarding access to knowledge, research and the diversity of cultural expressions and to ensure AI does not widen the technological divides within and between countries'.[14]

The third generation CHAT was applied to illustrate the interactions and tensioned spaces between two activity systems, as shown in Figure 1.6. The activity system on the left represents the factors involved in the CAPS or the intended curriculum as a mediating curriculum perspective (T). In contrast, the activity system on the right highlights the interplay between factors within the curriculum-as-lived, or the enacted curriculum (T), in preparation for enhancing 21st-century knowledge and skills.

In the first activity system, the educator (S) relies on the prescribed intended curriculum CAPS (R) to help students (O) achieve the intended outcomes within the specific contexts (C) of a school or TVET college. To effectively teach the intended curriculum, these educators must upskill their knowledge and skills through PD (L).

In contrast, the second activity system shows that the educator and student (S) collectively contribute to the taught curriculum by incorporating their own experiences and prior knowledge, which now serve as the experiential rule, the lived experiences of curriculum (R). This process



Source: Author's original diagram – self-generated in line with Figure 1.5, adapted with own information included.
Key: SDL, self-directed learning; CAPS, Curriculum and Assessment Policy Statement; TVET, Technical Vocational Education and Training; PD, professional development; HEIs, higher education institutions; T&L, teaching and learning.

FIGURE 1.6: Cultural-historical activity theory third generation indicating potential shared tensioned spaces – the blind spot.

14. See https://www.unesco.org/en/digital-education/artificial-intelligence. Accessed 12 August 2023.

fosters SDL, enabling students (O) to become autonomous learners not only in schools and TVET colleges but also in HEIs (C). Educators and students should implement their acquired knowledge and skills (L) with a commitment to fostering STEAME education for the future.

Using the third generation CHAT, it is possible to identify a potential shared tensioned space, or blind spot, along with factors influencing the taught curriculum and lived experiences, as illustrated in Figure 1.6. These factors include determining the knowledge and skills most valuable for the upcoming generation, particularly in the technology era. Additionally, reimagining the curriculum and pedagogical practices to support the necessary knowledge and skills, and integrating technologically informed pedagogical practices, especially in TVET, are crucial. Furthermore, the distinction between powerful knowledge from school versus lived experiences must be addressed. Collectively, these identified factors play a vital role in shaping the future of STEAME.

Adding to the argument, there is a large body of research which shows the chasm between the intended and the enacted curriculum. The CAPS for the STEM subjects [intended curriculum] place emphasis on developing 21st-century skills, enhancing SDL and utilising indigenous knowledge to contextualise curriculum themes for culturally diverse learners. Mentz and De Beer (2019) show that many of these lofty goals do not materialise in the classroom (the enacted curriculum), because of a 'washout effect' (Ziechner & Tabachnick 1981) caused by several factors. Many South African classrooms are still characterised by transmission-mode approaches (e.g. 'chalk-and-talk'), at the expense of problem-based and cooperative learning approaches which could enhance SDL. Utilising CHAT as a lens, these authors show how the annual teaching plans (ATPs) often inform the pedagogical choices that STEM teachers make. Instead of focusing on the principles that could enhance SDL ('Rules' in the activity system), the focus often is on managerialism and adhering to the ATP. Several tensions in the activity systems result in a 'contradiction of control' (McNeil 2013), widening the divide between the intended and enacted curriculum. Because of the inequality in the education system discussed earlier, many schools do not have the tools (e.g. well-equipped laboratories) to foster inquiry learning and SDL. STEAME educators (whether teachers or lecturers) are often not critical-reflective practitioners (division of labour) who experiment with engaging pedagogies and curriculum perspectives (tools) to enhance learning (Mentz & De Beer 2019). These factors all negatively impact on future-proofing STEAME education in South Africa.

Conclusion

This chapter sets the scene for a book for which the aim is to explore the conundrum of improving science education in a complex country, characterised by inequality. As Day and Bryce (2013, p. 53) comment, for teachers, both policy and we claim theory also, often lurk in the background, ‘somewhat disconnected from their normal classroom practice’. Utilising CHAT as a research lens, the book will explore the policy and practices that impact on classroom practice, as well as how the so-called theory-practice divide (Darling-Hammond 2006) could be overcome. As Igira and Gregory (2009) indicate, contradictions in an activity system could be a catapult for transformational change.

Chapter 2

Indigenous knowledge in the culturally diverse classroom

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Abstract

South African university campuses became warzones in 2015 and 2016, when students engaged in national protests, labelled by hashtags such as #RhodesMustFall and #FeesMustFall. This student unrest was fuelled by more than a demand for free tertiary education. Students also demanded epistemological access to higher education curricula, after decades of marginalisation under an apartheid regime. In the previous political dispensation, indigenous knowledge (IK) was marginalised. Today, there is a strong debate in South Africa on the decolonisation of the curriculum,

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and several scholars highlight the affordances of IK in doing so. Fuelled by embodied, situated and distributed cognition (ESDC) as a theoretical framework, it is claimed that IK holds affordances to make the school science curriculum more relevant for culturally diverse learners. The South African school curriculum advocates for the inclusion of IK into the Natural Sciences curriculum, and whereas some authors welcome this, other scholars disagree with such epistemological border-crossing, as they perceive IK as pseudoscience. Critics base their arguments on the tenets of Western science, namely, that it is 'objective' and inferential, whereas IK is characterised by its holistic, subjective and metaphysical nature. The leitmotif of this chapter is that the incorporation of IK in the school curriculum should firstly be based on sound theoretical frameworks and, secondly, that teacher professional development should focus on engaging pedagogies to facilitate such border-crossing.

■ Introduction

Despite the publishing of the South African Indigenous Knowledge Systems (IKS) Policy in 2001 (Department of Science and Technology 2001) (adopted by the South African Cabinet in 2004), as well as the publication of the Curriculum and Assessment Policy Statement (CAPS) documents for Natural Sciences, Physical Sciences as well as Life Sciences school curricula, proposing an integrated science-IKS curriculum in 2011, not much has changed at school level in terms of teachers implementing it in a meaningfully pedagogical manner. The fundamental purpose of the policy was to develop an appreciation, revalue and highlight the contributions that IKS practices and knowledges have made to modern science conceptions and practices. In addition, and more importantly, it proposed an integrated science-IKS curriculum. However, the CAPS policy falls short on how to pedagogically approach it for the teachers, who are the main enactors of this curriculum in the classroom setting (refer to the section on the intended and enacted curriculum in Chapter 1). The situation at the school level regarding teaching IKS is dire; many studies confirm that teachers still encounter difficulties when it comes to grasping what is meant by the concept 'indigenous knowledge' (De Villiers, De Beer & Golightly 2016; Jacobs 2015; Mentz & De Beer 2019), let alone teachers implementing an integrated science-IKS curriculum.

The same agency, honesty and bravery are needed as displayed by South Africans during the apartheid years, as well as in the past three decades following democracy, to move towards a more equal and just society. Gillian Schutte (2016) gave a brilliant account of an incident during the violent student unrests at South African universities, where the students demanded (in the spirit of the decolonisation of the curriculum) epistemological access to the curriculum:

> They looked brave and vulnerable. Their naked stomachs and breasts juxtaposed with police in riot gear armed with guns had a profound effect on all. The stark contrast was shocking and rendered the violence of men with guns and riot gear hyper-visible. Naked flesh exposed on the site of violence makes a visceral anti-war statement and this was war. It was a war declared by state and institution against the black child who dared to rise for their rights. Many dismiss the women's naked protest. They bemoaned the fact that yet again black women were forced to lose their dignity by stripping naked. But nakedness is not a loss of dignity when voluntarily used in protest. It is resistance against those who would strip them of their dignity. Women's breasts are a powerful semiotic of resistance. Breasts are the most vulnerable part of their bodies. They are also a source of nurturing. Even men with guns have been nourished on their mother's breasts. Breasts are both robust and vulnerable. These three half-naked women disarmed the police with their naked cries. The police did not fire their guns again. (De Beer 2019, p. 3)

A colonialised curriculum, which is typically characterised by its unrepresentative, inaccessible and privileged nature, often prevents students from identifying its values and contents (Le Grange 2019). It was this colonisation that led to the phenomenon that the Kenyan scholar Wa Thiong'o (1986) referred to as the 'colonisation of the mind'. The debate around the decolonisation of the curriculum received new momentum in South Africa with the student protests in 2015, yet there is no agreement among scholars and curriculum developers on how such decolonisation should occur. Some scholars argue for an inclusive curriculum, which would allow epistemological access to culturally diverse students. For others, an inclusive curriculum is not enough, as such critics claim that it is an attempt to cut politics and power out of the equation. The latter authors emphasise that power relations in the curriculum should be acknowledged. Against this background, this chapter shares various views on how indigenous knowledge (IK) could enhance an attempt to decolonise the Natural Sciences school curriculum.

■ The conundrum of incorporating indigenous knowledge in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship curriculum themes

The incorporation of IK into science education should be seen in the context of the disconnect between African students' IK and the scientific knowledge taught in schools, as highlighted by Nnadozie (2009). This disconnection is primarily because of the lack of relevance of science education to the everyday lives of African people. Also, some scholars view IK as pseudoscience, which also hinders epistemological border-crossing. For example, Widdowson and Howard (2008, p. 242) described IK as 'junk science'.

To achieve meaningful and effective science learning, it is essential to recognise that learners bring pre-existing knowledge, including traditional knowledge acquired from their real-world experiences, which should be integrated into science education. Mavuso, Olawale and Mkosi (2021) argue that the inclusion of IKS has been introduced in the South African curriculum, specifically in the Curriculum 2005 Natural Science Policy. Therefore, the focus should shift from advocating for inclusion to identifying the most effective methods for successful implementation. While the revised National Curriculum Statement supports IKS integration, teachers still require adequate training. A standardised IKS curriculum offers the best opportunity for teachers to incorporate this concept, considering they are more likely to teach what is already familiar (Mavuso et al. 2021).

Two major reasons why IK does not find its rightful place in the Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) classroom are (1) the lack of theoretical frameworks underpinning such border-crossing and (2) the lack of suitable engaging pedagogies to foster teaching and learning. In this chapter, both these concerns are addressed.

Theoretical frameworks underpinning the epistemological border-crossing

One of the reasons why the CAPS principle that IK should be integrated in Science, Technology, Engineering, Mathematics (STEM) curriculum themes is not realised is the lack of supporting theoretical frameworks. This results in the practice that mere lip service is paid to IK in the classroom (De Beer 2019). In this section, we propose a number of theoretical frameworks that could be considered in such epistemological border-crossing: social constructivism, ESDC, Gardner's multiple intelligences (MI) and multi-modal learning, and critical theory.

Social constructivism

Social constructivism serves as a sound theoretical framework when arguing for the inclusion of IK. Vygotsky's (1978) construct of the zone of proximal development (ZPD) is a useful heuristic when planning learning opportunities to incorporate IK in curriculum themes. When scaffolding learning across the ZPD (from the actual to the potential development), semiotic tools are used. These tools could be language, IK artefacts or practices, or engaging pedagogies (e.g. story-telling or problem-based learning). De Beer (2019) emphasises the importance of collaboration with practitioners (holders of IK), who could be seen as the 'more knowledgeable other' (Vygotsky 1978).

Neuroscience, and embodied, situated and distributed cognition

Advances in neuroscience made us understand that cognition is not just limited to symbolic processing in the brain. Learning entails more than simply chemical synaptic transmission and communication between neurons and the brain. The argument for the inclusion of IK in the school curriculum is often based on ESDC (Hardy-Vallee & Payette 2008) as a theoretical lens. Chahine (2013, p. 434) highlights that ESDC postulates that 'cognition is physiologically embodied, socioculturally situated, and ostensibly distributed among individuals'. Chahine explains that 'bodily movement, use of manipulatives, acts of drawing pictorial displays, verbal language, use of written symbols, play a role in understanding concepts' (Chahine 2013, p. 435). By engaging learners in tasks such as Zulu beadwork (ethnomathematics) or the Kirby-Bauer laboratory protocol to determine the antimicrobial properties of medicinal plants (ethnobotany), multimodal learning takes place that could enhance conceptual understanding.

Multiple intelligences and multimodal learning

Howard Gardner developed his MI theory in 1983. Gardner defined intelligence as 'a biophysical potential of our species to process certain kinds of information in certain kinds of ways' (Suprapto, Liu & Ku 2017, p. 215). Gardner's theory proposes eight distinct intelligences (verbal/linguistic, musical, logical-mathematical, visual/spatial, bodily-kinesthetic, intrapersonal, interpersonal and naturalistic intelligence). Gardner later added existential intelligence, which focuses on 'fundamental questions about existence, life, death' (Roberts 2010, p. 242). This additional and 'tentative' addition is probably the reason why Gardner (2012) himself refers to his 8½ intelligences. Being cognisant of these MI opens up opportunities for multimodal learning opportunities in the classroom, when engaging with IK.

Critical theory and Derrida's insights

One could also look at such epistemological border-crossing in the classroom through the lens of Derrida's philosophy. One of the reasons why some scholars claim IK should be excluded from the Natural Sciences curricula is that IK lacks the so-called objectivity that characterises the natural sciences. Derrida's work makes it clear that no discourse can claim to be objective, and he exposed the 'pretensions to objective knowledge' (Ezeanya-Esiobu 2019). Derrida's construct of Anti-Logocentrism is important, as it describes how there cannot be a universal truth, as truth is contingent or contextual (Derrida 1982; Sahu, Sarangi & Mallik 2021). This can be illustrated with an ethnobotany example of metaphysical plant use and the rationality thereof in a South African context. Impinda (*Adenia gummifera*) is a plant sold at many traditional markets in South Africa. A decoction of the plant is often sprinkled around the house to keep 'evil spirits' away (Van Wyk 2015). This plant has active ingredients (alkaloids) with powerful antimicrobial properties. Just as people use bleaches and antiseptic products in the kitchen and bathroom to kill microorganisms, the use of impinda performs the same function. The use of the plant therefore makes rational sense – but the context should be taken into consideration. It is important to take note of the work of St. Clair (2000, p. 86), which shows that metaphors in cultural language provide a perspective on knowledge just as scientific paradigms provide a perspective on theoretical knowledge. The current dichotomy between 'Western science' and IK, and the superiority of Western science perspectives, could be scrutinised through a deconstruction (Derrida 1976) lens. Western scholars' perceptions of IK often perpetuate dualist views of true/false or objective/subjective. In the process, learners are deprived of the affordances that IK holds to contextualise Western science to culturally diverse learners – whether they are Khoisan or Zulu learners in South Africa – or Indian learners who subscribe to the rich cultural heritage of Ayurveda.

Demystifying the nature of indigenous knowledge systems (NOIKS)

Teachers should have a sound working knowledge and understanding of what IKS is to be able to make sense of how the science worldview relates to the IKS worldview in order to create meaningful connections with the science and IK content in the curriculum.

Indigenous knowledge (IK) essentially is:

- *Tacit*: In essence, it was essentially transmitted orally, or through imitation and demonstration. It was therefore not easily arranged in a systematic collection of 'data' as its characteristic features may be lost.

- *Locally located*: It is embedded in a specific society and established within strong conventions, as it is generated by the individual experiences of members within that specific local community (Berkes 1993).
- Holistic: It is interrelated with art, dance, music and stories linking people to their environment (Mitchie & Linkson 2000), where science and ethics are also intertwined (Aikenhead & Ogawa 2007; Berkes 1993; Mitchie & Linkson 2000). Indigenous knowledge does not separate the empirical and experiential from the spiritual and intuitive (Nakashima & Roué 2002), as separation into distinct categories could lead to the potential risk of dislocating IK and could pose challenges if integration could take place.
- *Experiential*: Individual observation, intuition, trial and error, and consolidation of facts drive IK. This means that indigenous people have acquired their knowledge over long periods through their direct engagement with nature (Bernhardt & Kawagley 2005; Islam 2012). It, therefore, 'develops through rational, empirical means and has been tested in nature over many generations – a process that authenticates' its relevancy and use (Khupe 2014).
- *Relational*: Indigenous people have an understanding of botany, medicine chemistry and astronomy. Every aspect of their knowledge relates to each other and is not compartmentalised as in modern science (Bernhardt & Kawagley 2005).
- *Spatially based*: Indigenous people think in terms of space as opposed to time (Aikenhead & Ogawa 2007). Thus, indigenous people will, for example, look at the changing of the seasons as particular anchors for when to sow and reap.
- *Dynamic*: Just as modern science is continuously changing as a result of new or inconsistent evidence, so too is IK. This is evidenced by the survival of indigenous individuals and communities over time (Aikenhead & Ogawa 2007).

At best, IK and modern science can be regarded as complementary or parallel systems of knowledge, instead of fundamentally incommensurable.

In Table 2.1, IK and modern science paradigms are compared.

The above nuanced understandings need to be built into any programme where IKS need to be demystified first and foremost and supplemented with real practical hands-on activities for teachers to make the mindset shift and embrace the value that IK affords and how it strengthens and supports the science that can be taught in their classrooms.

TABLE 2.1: Comparing indigenous knowledge and modern science paradigms.

Aspect of knowledge	Indigenous paradigm	Modern science paradigm
Transfer	• Observation and practice • Orally transmitted through storytelling	• Formal education – didactic • Transmitted through a collection of written works in the form of books
Acquisition	• Knowledge acquired over long periods (Islam 2012)	• Knowledge acquired over short time spans (Islam 2012)
Framework	• Spiritually framed • Science and ethics are intertwined • Art, dance, music and stories link people with their environment (Mitchie & Linkson 2000) • Local – each community has a deep embedded knowledge about their own environment	• Mechanistically framed (Berkes 1993) • Value free (Berkes 1993) • Evidence is presented in terms of observations, theories, predictions and experimental confirmation (Michie & Linkson 1999) • Global or universally framed
Style/ methodology	• Contextualised – deeply rooted in everyday life and the environment • Experiential – individual observation, trial and error, and consolidation of facts • Subjective • Cyclical modelling	• Decontextualised – content is abstract • Positivist – experimentation and methodical, calculated collection of facts • Objective • Linear modelling
Approach	• Holistic and interrelated. It is concerned with relational aspects (Aikenhead & Ogawa 2007; Berkes 1993; Mitchie & Linkson 2000) • Intuitive • Does not separate the experiential and empirical from the spiritual and intuitive (Nakashima & Roué 2002) • Contributes to sustainability – deep knowledge is relational knowledge (Nakashima & Roué 2002) • Ecologically based – notion of sustainability/renewal says that there are regular patterns in nature to search for to sustain our continued existence (Mitchie & Linkson 2000)	• Fragmented and isolated (reductionist) based on subsets of the whole (Berkes 1993) • Analytical • Oppositions of secular to the spiritual; environment and society; empirical and symbolic (Nakashima & Roué 2002) • Pathways between natural and social realms are not included in world concepts (Nakashima & Roué 2002) • Phylogenic relationship based • No direct connection between researchers and ecology (Mitchie & Linkson 2000)
Aims	• Long-term wisdom • Ecological sustainability	• Short-term prediction • Economic sustainability
Language	• Tacit • Native language is used but thinking does not occur within the boundaries of language (Islam 2012) • Action orientated	• Explicit • Adopts the language of mathematics/ measurement (Islam 2012) • Abstract orientated

Source: Authors' own work.

Different perspectives on the infusion of indigenous knowledge in the Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship classroom

Despite the epistemological and ontological similarities between the two knowledge systems, the differences between IK (e.g. its holistic nature) and Western science (e.g. its reductionist nature) lead to a disagreement among scholars on whether IK should be included in the school STEM (or, as advocated in this book, STEAME) curriculum. Various perspectives on the relationship between Western science and IK will now be discussed, that is, the inclusive, exclusive and overlapping domain outlooks.

The inclusive perspective

The inclusive perspective argues that IK is part of science. Ogunniyi (2004) argues that 'Western science evolved from the indigenous sciences of the Egyptians, Babylonians, Persians, Arabs, Indians, Mexicans and Chinese'. For this reason, IK should be seen as part of the fabric of modern science.

The exclusive perspective

Zinyeka, Onwu and Braun (2016) highlight that this perspective views IK and modern science as two different, independent knowledge domains. Cobern and Loving (2001), for example, hold the view that IK as a valid knowledge system should stand on its own and not be integrated with modern science.

The overlapping (intersecting domains) perspective

This perspective acknowledges both the similarities and uniqueness of both knowledge systems. There is overlap in terms of shared tenets (e.g. both knowledge systems are empirical and inferential), but this stance also acknowledges that there are fundamental differences, for example, whereas modern science is reductionist, IKS is holistic.

This is a perspective that could be very useful in the STEAME classroom. Learning activities tapping into the shared tenets like the empirical and inferential nature of the two knowledge systems could include the Kirby-Bauer technique to test the antimicrobial activity of medicinal plants that are culturally used. De Beer and Whitlock (2009) show how engagement in a simplified Kirby-Bauer technique (Mitchell & Cater 2000) could teach learners about the tenets of both science and IK, as they hypothesise, follow laboratory techniques and make careful observations. If a plant is traditionally being used to treat a bacterial or fungal infection, learners could possibly hypothesise that active ingredients (e.g. alkaloids) in the plant would be able to kill the pathogens causing the disorder. This can then be tested in the school laboratory, using the Kirby-Bauer technique. The procedure entails that non-pathogenic bacteria are grown on an agar medium in a petri dish. Learners would then put some plant extract onto the agar medium. Clear zones will develop on the agar plate if the plant extract is indeed effective. This activity allows learners to engage in scientific inquiry and not merely pay lip service to IK (e.g. a teacher mentioning one or two culturally important medicinal plants such as devil's claw).

The above example of the Kirby-Bauer technique does pose a challenge, in so far that Western science techniques are used to validate IK. This could be a valuable discussion in the STEAME classroom, which would provide learners with a more nuanced understanding of the nature of science and IK. Gratani et al. (2011) warn that:

> *[T]*he validity of one knowledge system must be confirmed by another, raises issues over the equity of such an approach. The risk is that the superiority currently held by scientific knowledge is perpetuated if validation of indigenous knowledge is achieved by either adopting scientific knowledge as the standard against which IK must be measured, or by accepting only scientific evidence to support IK. (p. 2)

■ The proposed pedagogical model for this epistemological border-crossing

Pedagogy refers to the theory, practice and methods used in the education and instruction of learners. It encompasses the principles, strategies and techniques employed by teachers and educators to facilitate learning and promote the development of knowledge, skills, attitudes and values in students. Pedagogy involves a range of considerations, such as the selection and organisation of educational content, the design of learning activities, the assessment of student progress and the overall instructional approach. It encompasses both the art and science of teaching, incorporating educational theories, research findings and practical experience to create effective learning environments. Effective pedagogy considers the diverse needs, backgrounds and learning styles of students and strives to create engaging, interactive and inclusive learning experiences. It may involve a variety of instructional methods, such as lectures, discussions, group work, problem-solving activities, hands-on experiments, technology integration and more, depending on the subject matter, educational goals and the specific needs of learners.

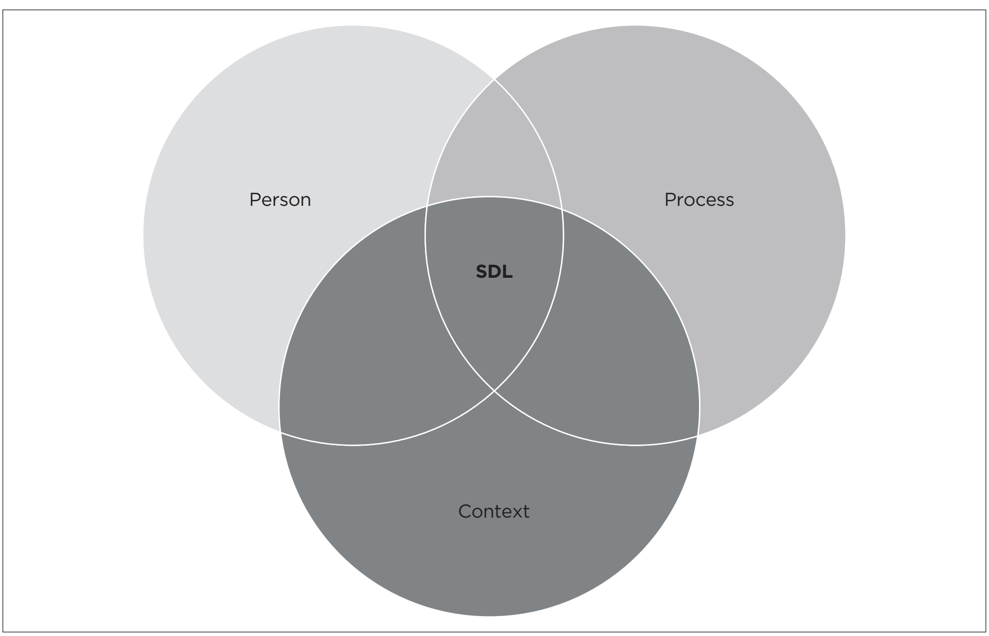
Ideally, a pedagogical model for IK border-crossing should be built on self-directed learning principles. Knowles (1975) described self-directed learning as a:

> *[P]*rocess in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources, choosing and implementing appropriate learning strategies and evaluating learning outcomes. (p. 18)

Two pedagogies that have been shown to enhance self-directed learning are problem-based and cooperative learning strategies.

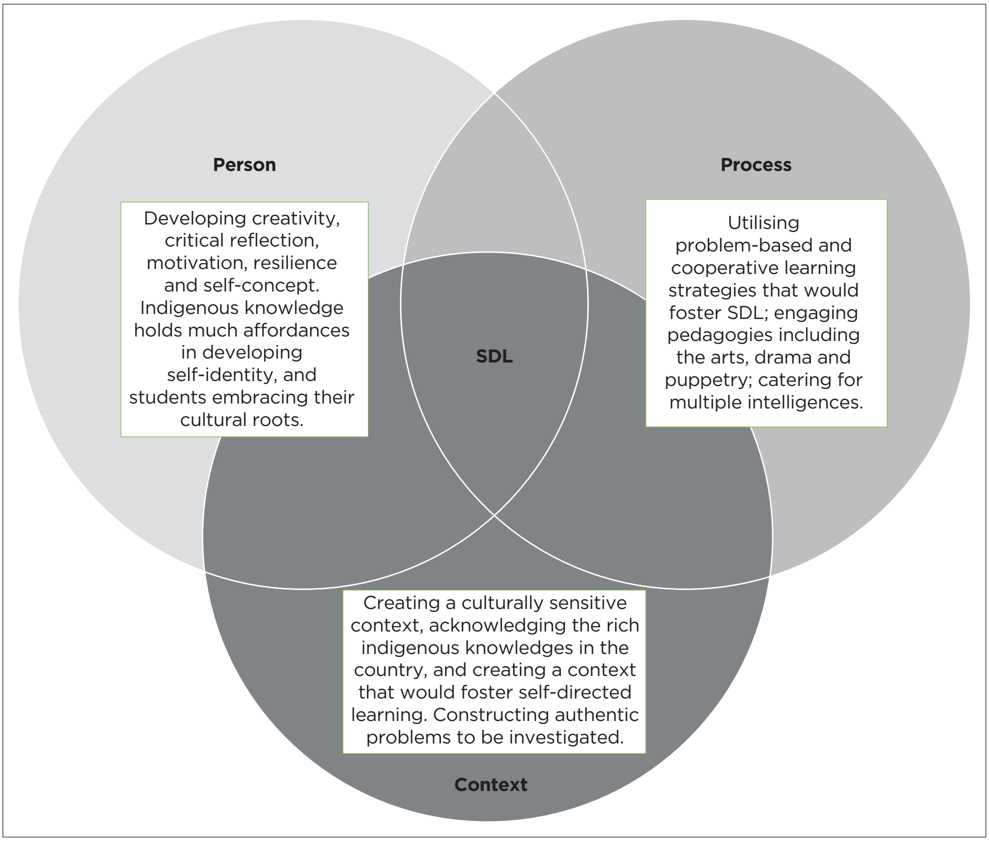
Hiemstra and Brockett developed the person-process-context (PPC) model for self-directed learning (see Figure 2.1), and this served as the basis for the proposed model for infusing IK in the STEAME curriculum.

We propose the pedagogical model for epistemological border-crossing as illustrated in Figure 2.2.



Source: Hiemstra and Brockett (2012).
Key: SDL, self-directed learning.

FIGURE 2.1: Hiemstra and Brockett's (2012) person-process-context model for self-directed learning.



Source: Hiemstra and Brockett (2012).
Key: SDL, self-directed learning.

FIGURE 2.2: The proposed pedagogical model for epistemological border-crossing (based on the model of Hiemstra and Brockett).

The person perspective

De Beer and Mentz (2019) claim that the holders of IK traditionally are self-directed learners, who have to solve authentic problems in a unique context, using creative and critical thinking. This model emphasises the further development of the 'characteristics of a self-directed learner, such as creativity, critical reflection, motivation, resilience and self-concept' part (Hiemstra & Brockett 2012, p. 158). Indigenous knowledge holds much affordances in developing self-identity and students embracing their cultural roots. It also allows for multiple intelligence perspectives (Gardner 2012) in teaching and learning, and better contextualising the curriculum content for diverse learners.

The process perspective

The process domain refers to 'the teaching-learning transaction, including facilitation, learning skills, learning styles, planning, organising and technological skills' (Hiemstra & Brockett 2012, p. 158). Holders of IK were per definition self-directed learners. The focus should be on utilising pedagogies that would foster self-directed learning (SDL), such as problem-based learning and cooperative learning. Also, IK is embedded in oral traditions such as story-telling, and music, opening the avenues for arts-based pedagogies. For example, puppetry could be a useful strategy to utilise in the STEAME classroom.

The context perspective

Often, the 'context' dimension in SDL is marginalised (Merriam 2001). Candy (1991, p. 311) is of the opinion that '[the] term self-direction has misled many into elevating the individual above the collective – but the nature of knowledge and learning inherently puts learners in relationship with others'. IK creates a context where learners could, through engaging pedagogies and multimodal approaches, develop as self-directed learners. Two critical elements in the context are that (1) an authentic problem should be investigated and (2) cooperative learning principles should be the foundation (i.e. 'positive interdependence, individual accountability, face-to-face promotive interaction, interpersonal and small-group skills, and group processing') (Johnson & Johnson 2019). Indigenous knowledge also provides a unique context for learners to engage in the syntactical nature of the subject (the tenets of the natural sciences).

A research perspective: The contiguity argumentation model

While theories, models and pedagogies are useful underpinning tools, researchers in the area of curriculum and policy developments in human sciences and education require an active analytical tool to interpret nuances of the expression of an integrated science-IKS curriculum.

One such effective analytical tool is the contiguity argumentation theory (CAT) as mooted by Ogunniyi (2009) and is rooted in the Aristotelian Contiguity Theory. This theory of the structure and organisation of two distinct coexisting thought systems, such as the worldview of science and the worldview of IK, leads to an adaptation of contextual change in the cognitive spaces of experience.

Accordingly, five cognitive categories are noted and listed in Table 2.2.

TABLE 2.2: Cognitive states of the contiguity argumentation theory.

Cognitive states	Description
Dominant	It is an idea characterised or supported by a very strong explanation that is accepted socially, for example, a scientific explanation of lightning in terms of static electricity as opposed to the explanation offered for the same phenomenon within an indigenous worldview.
Suppressed	In this case, an idea becomes suppressed if more valid, testable evidence or established social norms, for example, the scientific explanation of the cause of a particular disease may be suppressed in the face of local cultural beliefs about possible negative and nefarious motives of enemies behind the disease.
Assimilatory	A less powerful idea may be assimilated into a more powerful idea in terms of persuasiveness or adaptability of the dominant idea in a given context, for example, the indigenous idea of not leaning against a metal pole, tree or wall which may have arisen from experience can be easily assimilated into the scientific concept of lightning as an electrical phenomenon.
Emergent	In the case where no prior idea existed before a new one can be or has to be newly acquired or developed. Examples can include a number of scientific concepts such as atoms, molecules, magnetism, conservation of matter and laws of motion, which have usually been learnt from school science.
Equipollent	When two competing ideas have equal intellectual strength, the ideas tend to co-exist without necessarily resulting in a conflict, for example, evolution and creationism.

Source: Ogunniyi (2002); Ogunniyi and Hewson (2008, pp. 143–153).

This theory resonates with Jegedes' (1995, pp. 80–101) theory of collateral learning and is useful for teachers to use when navigating through reflections, transcripts and opinions expressed by learners on topics of an integrated science-IKS curriculum, thus working through disparate knowledge traditions in an equitable way (Langenhoven 2009, pp. 74–80; Le Grange 2008, pp. 817–826).

Creating teaching and learning spaces for a learner-centred science classroom: The affordances of the dialogical argumentation instructional model

In Figure 2.2, the PPC model for SDL has been explained. The science classroom should be characterised by a learning context that would enhance self-directed learning. Science teachers have the arduous task of navigating an epistemology of an integrated science-IKS curriculum, hence an effective scaffolding instructional model, namely, the dialogical argumentation instructional model (DAIM) is suggested, as a way to encourage learner participation.

Effective pedagogy takes into account the diverse needs, backgrounds and learning styles of students and strives to create engaging, interactive and inclusive learning experiences. It may involve a variety of instructional methods, such as lectures, discussions, group work, problem-solving activities, hands-on experiments, technology integration and more, depending on the subject matter, educational goals and the specific needs of learners.

A DAIM is a scaffolding framework that creates critical discursive spaces for teachers and learners. By acknowledging the voices of diverse cultures in a multi-cultural classroom, a harmonious blend of ideas is given expression. In this way, meaningful connections between subject disciplines and socio-cultural beliefs are given credence whereby the focus is on learners to persuade, convince, express doubts, ask questions and relate views and opinions by discussing Western worldviews and IK worldviews. This approach leads to a consensus agreement on the issues being argued, for or against, as a form of cognitive harmonisation (Diwu, Ogunniyi & Langenhoven 2011; Langenhoven 2009; Langenhoven & Ogunniyi 2011; Lazarus 2004; Skoumios 2009).

The DAIM is underpinned by CAT (Nhalavilo & Ogunniyi 2011), and this argumentation approach to teaching and learning allows both teachers and learners to become active partners in constructing (making meaning) of their own knowledge contribution.

A positive implication of this approach is giving each participant a voice of expression in the following ways:

1. individually by constructing his or her own meaning and knowledge
2. in a group dialogue whereby a second chance is afforded to evaluate his or her own knowledge or understanding in relation to others' views
3. in the whole class on the same issue/debate by understanding the views and opinions of others, and finally
4. the views of the facilitator (teacher) who tracks, categorises and identifies trends in order to assist learners to reach a level of cognitive harmonisation of understanding.

Rationale for the use of argumentation

Scientific claims are based on some beliefs, evidence from experimental data and observations. Extant works from the philosophy and history of science (HOS) premised upon affordances of scientific claims are what make the scientific enterprise an argumentative exercise.

Among the numerous argumentation frameworks in the extant literature, Toulman's argumentation pattern (TAP) and CAT are found to be useful. Toulman's argumentation pattern follows school science logic by employing the scientific method and using a logical approach to analysis. Contiguity argumentation theory on the other hand seeks to explain learners shifting argumentation positions in their metaphysical understanding as influenced by religion, beliefs and worldviews.

The dialogical argumentation instructional model

Table 2.3 illustrates the DAIM in an integrated science-IKS curriculum.

TABLE 2.3: Nascent model to teach aspects of an integrated science-indigenous knowledge systems curriculum.

Steps	Activity	Learner role	Teacher role
Step 1	Nodal Point	Considers questions related to the socio-cultural-scientific issue/concept	Provides a socio-cultural-scientific issue/concept as related to the curriculum and explains the DAIM process
Step 2	Individual thinking (intra-argumentation)	Interprets the science-IKS issue and records a personal view/opinion	Facilitates the process by keeping learners on task using rhetorical questioning
Step 3	Group sharing thinking (inter-argumentation)	Small groups (three to four) where opinions related to the topic are shared; group members negotiate a final consensus response	Facilitates the learning environment with writing and recording material, for example, worksheets
Step 4	Whole class thinking (trans-argumentation)	One member presents the final consensus position to the whole class	Facilitates the process by displaying, categorising and identifying trends and keywords
Step 5	Teacher – learners consolidation (meta-argumentation)	A final consensus position is negotiated; thinking about the thinking process	Facilitates cognition, dissonance, divergence, misconceptions, claims, counterclaims and nascent knowledge
Step 6	Reflection (cognitive harmonisation)	Critical cognition ensures that cognitive harmonisation (agreement) is attained	Reflects by managing focus group interviews for TAP and CAT analysis

Source: Based on Ogunniyi (2007a, 2007b).
Key: DAIM, dialogical argumentation instructional model; SDL, self-directed learning; PPC, person-process-context; IKS, indigenous knowledge systems; TAP, Toulman's argumentation pattern; CAT, contiguity argumentation theory.

Implications for teacher education (pre-service and in-service education)

Resource development

Student teachers at higher learning institutions enrolled for science education degrees are exposed to focused courses in the HOS, nature of science (NOS) and the nature of IKS (NOIKS). This exposure should enable them to be agents of change. The University of the Western Cape (UWC) experience is that, in the first instance, it demystified the concepts, developing a meaningful understanding of how science and IKS function and how to bring the two together without creating a tension between the two worldviews (Dinie n.d.). They are able to develop pedagogically sound videos and written narratives that unpack selected science concepts in the CAPS curriculum in the context of the equivalent IK concept and vice versa.

Student teachers have to show how the IK concept relates to the science concept and the underlying science principles, the IK concept being backed or explained by science research and scientific principles. We would like to illustrate this with a few examples.

The use of underground cooking in an IK context can clearly demonstrate and explain the concepts of radiation, convection, evaporation and conduction. Similarly, when looking at the principles of filtering water, a clear connection can be shown with the different layers of soil beneath a river bed that act as filter layers, which can be demonstrated through the making of a water filter using a plastic bottle with the different layer types of soil to show how the principles of this technology was observed in nature and in response to a need, copied from nature to filter their water.

Another example is the use of cow dung on rondavel floors. It is mixed with water and applied to rondavel floors and after drying, polished to a shine. Current science research indicates that cow dung possesses antibacterial properties in addition to its shine from the fats it contains, giving it a hygienic component.

Much enthusiasm was displayed by students developing these resources during the courses at the higher education (HE) level, but feedback from teachers once they start teaching is there is very little space for them to explore these IKS-science further because of the loaded annual teaching plans (ATPs) as well as the amount of content which need to covered, but also the very little, if any space allocated for the IKS-science sections in the curriculum (Dinie n.d.).

Sensitising student teachers/teachers to engaging pedagogies, such as the use of puppetry for teaching and learning

Puppetry holds the possibility of being used as a versatile tool that can be incredibly valuable in both science education and the preservation and transmission of IK.

Table 2.4 shows some of the advantages of using puppetry in teaching both science and IK.

Looking at the possible use of puppetry in fostering a positive view of the particular nature of IK with its cultural nuances and meanings, it appears to foster the support of:

1. *Cultural preservation*: Puppets can be used to preserve and pass down traditional stories, cultural practices and IK from one generation to another, as has always been the case with oral histories.

2. *Language preservation*: Puppetry aids in preserving indigenous languages by using them in storytelling and performance, helping keep languages alive.
3. *Connection to nature*: Many indigenous cultures have deep knowledge about the natural world; puppets can represent animals, plants, or natural phenomena, serving as educational tools to teach about ecosystems, biodiversity and ecological wisdom.
4. *Community engagement*: Puppetry performances can bring communities together, fostering a sense of pride and identity in their cultural heritage and knowledge.

TABLE 2.4: The affordances of puppetry in facilitating.

The teaching of both science and indigenous knowledge using puppetry allows for:
Visualisation
Puppets can help visualise complex scientific and IK concepts, making them more accessible and engaging for learners of all ages
Storytelling
They facilitate storytelling, allowing educators to create narratives that explain scientific theories, IK stories or historical scientific and IK discoveries
Interactive learning
Puppets encourage interactive learning experiences, where students can interact with the puppets, ask questions and participate in discussions, fostering better understanding
Experimental demonstrations
Puppetry can be used to demonstrate scientific experiments and IK processes or procedures in a controlled and entertaining manner
Engagement and creativity
They stimulate creativity and imagination, encouraging students to think outside the box and explore scientific and indigenous concepts in innovative ways

Source: Authors' own work.
Key: IK, indigenous knowledge.

It would therefore appear that combining puppetry with science education and IK learning creates dynamic and engaging methods of teaching and sharing information. It allows for a more immersive and memorable learning experience that resonates with diverse audiences, catering to different learning styles and cultural backgrounds.

■ The affordances of indigenous knowledge in the development of an entrepreneurial mindset and ethics

If learners are exposed to a hands-on approach to, for example, plant-based IK, which includes knowledge of different kinds of plants for different authentic health uses, a whole industry can be built with the growing and distribution of these plants. These different plant uses can be authenticated and validated through triangulation of traditional herb specialist healers in communities. Although we personally would not advocate the development of specific remedies in the forms of potions to be developed by the growers themselves, unless they have specific validated and authentic knowledge on how to prepare these potions, it is a good topic for discussion in the classroom. In this sense, it would create another layer for the authentic traditional healers to start upscaling their potions making, adding another layer to job creation, apart from the advantage of making their authentic products more easily available and to up the scale, moving society away from the harmful effects of traditional drugs on the market. It would also ensure the effect and/or acknowledgement gets given to the intellectual property capital of these cultural capital bearers.

There is also the opportunity to upscale, for example, simple home remedies, for example, facial care remedies, using simple plant extracts of Aloe, the use of clay as a skin purifying agent as well as the traditional growing and supplying of common roots as ginger, garlic, turmeric, etc., which are very expensive today. This market could easily be tapped for job creation, with clear product standards set to ensure quality products.

We conclude this section by providing an example from the Tsonga people in Giyani in South Africa. They have been using *Lippia javanica*, the fever tree, for decades as an insect repellent. In conjunction with the local community, the Council for Scientific and Industrialized Research researched the manufacturing of candles using the oils of the fever tree. Van Wyk and Gericke (2018) showed that the volatile oil of the plant contains myrcene, caryophyllene, linalool and ipsdienone, which are highly effective as an insect repellent. The candles produced are sold, and the profits are ploughed back into the community. The infusion of IK in the science classroom could assist learners in developing an entrepreneurial mindset – an attribute very essential in a country that has very high unemployment figures.

■ Conclusion

The epistemological border-crossing of IK and Western science is nascent scholarship, and the chapter highlighted the fact that science education scholars are not in agreement on the role of IK in the STEAME curriculum. The chapter highlighted the many affordances of IK in a STEAME context, especially in a culturally diverse country like South Africa.

Finally, as educators and trainers of educators, it is crucial for us to consistently acknowledge the significance and interplay between linking our learners' everyday social experiences and cultural capital to the process of acquiring and negotiating knowledge and understanding in our science classrooms. Dewey (1956) captures this essence perfectly by stating:

> From the standpoint of the child, the great waste in the school comes from his inability to utilise the experiences he gets outside the school in any complete and free way within the school itself; while, on the other hand, he is unable to apply in daily life what he is learning at school. That is the isolation of the school – its isolation from life. (pp. 75–76)

Chapter 3

The affordances of Change Laboratories for systemic change

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Abstract

With the shift from the traditional Science, Technology, Engineering, Mathematics (STEM) grouping to a more holistic Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) approach comes a need for teacher professional development. Such a more

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multi-disciplinary approach to the natural sciences should still adhere to the tenets of science. It is therefore essential to support science teachers in strengthening their pedagogical content knowledge and to have more nuanced understandings of the nature of science. Research shows that professional teacher development (PTD) interventions are not always very effective. This chapter focuses on the affordances of cultural-historical activity theory (CHAT) in PTD. The past decade or two saw third-generation CHAT as a research lens gaining momentum. However, there are nowadays more voices arguing for fourth-generation CHAT perspectives, with a much broader and holistic perspective on teacher professional development. All the different stakeholders should be involved in the planning of teacher professional development interventions, if we would like to see systemic change. In this chapter, nascent research on Change Laboratories and the utilisation of fourth-generation CHAT is shared. The authors argue that fourth-generation CHAT is a versatile research lens in the South African context to identify and address barriers in the promotion of STEAME education in the classroom. Change Laboratories can be used to manage educational change, and for this research, they entail that all stakeholders in education – the teachers, school management, Department of Basic Education (DBE), parents, learners, teacher unions and governing bodies – will be involved in the planning and development of new and innovative strategies needed for the 21st century and Fourth Industrial Revolution (4IR) in terms of teacher professional development that can enhance education in South Africa and contribute to lifelong self-directed learning among our learners. However, this chapter focuses on the challenges faced, as each of the different activity systems experiences tensions that further contribute to what Engeström (1987 [2015]) refers to as a run-away object. The context of this chapter is continuous professional teacher development (CPTD) in the Western Cape province, and the authors explore how Change Laboratories could result in more effective CPTD.

■ Introduction

Payne (2008), in an American context, speaks of 'so much reform, so little change'. This is equally true of the South African sector. The South African education sector has been characterised by several curriculum- and policy changes, yet research shows that the same perennial problems keep on haunting the education sector. Research carried out on teacher professional development interventions shows that there often is limited transfer of new knowledge and skills to the post-intervention classroom (De Beer 2019). Large amounts of funding are invested in teacher professional development, yet it is an open question on whether this equates to improvement in teaching and learning. Very often, such interventions, albeit very good programmes, result in the so-called wash-out effect, where teachers, after such professional development, fall back on old practices

(Zeichner & Tabachnick 1981). Teachers often cite systemic tensions as the reason for the lack of reformed teaching practices in the classroom. Several reasons are provided for such a lack of reformed teaching practices: the excessive focus on achievement in summative assessment tasks (such as the National Senior Certificate [NSC]), as well as the full school curriculum and the annual teaching programme (ATP) (De Beer 2019).

Another problem is one of bureaucracy. 'We are trying to solve a problem that requires professional skill and expertise by using bureaucratic levers of requirements and regulations' (Mehta 2013, p. 2). Mehta (2013, p. 2) is of the opinion that we are asking the wrong question. When teacher professional development does not produce the desired effects, we often ask the question, 'What's wrong with the reform?'. Instead, we should be asking the question, 'What's wrong with the sector?'. The latter author is of the opinion that education in essence is based on a core system imbedded in bureaucracy, rather as a profession. According to Mehta (2013, p. 2), professional development of teachers is often underpinned by 'bureaucratic levers of requirements and regulations', rather than professional skill development as the driver for the process.

According to Mehta (2013, p. 9), there are two models of organising the work. The first is the bureaucratic model, which is organised around the logic of managerial control – a model which sadly manifests in how school education is governed. In contrast, the professional model advocates for high levels of skill and expertise (Rowan 1990) and high levels of teacher agency. The professional model forefronts self-directed learning, as teachers need to take responsibility for their own professional development, which is not necessarily the case with the bureaucratic model.

Table 3.1 summarises these two models.

Although the Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education discourse already started in 2006,

TABLE 3.1: The bureaucratic and professional modes of organisation.

Dimension	Bureaucracy	Profession
Nature of work	Routine; compliance	Skilled/professional; creative
Coordinating mechanism	Standardisation of work processes	Standardisation of skills through training and licensing
Source of authority	Managerial control	Knowledge of the work
Location of authority	Administrative class	Practitioner class
Responsibility of practitioners	Implement directives from above	Self-regulating guild: The field sets standards; individual practitioners exercise judgement and discretion within those standards
Political dynamics	Hierarchical: Strong state, weak practitioner class	Countervailing powers: Profession and state have relatively equal footing

Source: Adapted from Metha (2013, p. 37) and Mintzberg (1993).

the past two decades did not ensure an established and robust body of research (Marín-Marín et al. 2021). The latter authors highlight that reasons for this shift towards STEAME education include arguments related to gender- and racial differences, skill sets developed by students, and teacher professional development to pay justice to the STEAME agenda. In this chapter, we argue that in a professional model, in which self-directed learning is foregrounded, inputs by all stakeholders might ensure systemic impact and educational reform.

Methodology

This is a theoretical, conceptual chapter, focusing on the affordances of Change Laboratories and fourth-generation cultural-historical activity theory (CHAT) for continuous teacher professional development. A concept paper discloses new ideas, before full validation. A literature review of this nascent field was done, and it is supported by preliminary qualitative data, emanating from a Change Laboratory project initiated by the University of the Western Cape (UWC) and the Western Cape Education Department (WCED). This chapter disseminates the views of a Senior Education Specialist in the WCED on continuous professional teacher development (CPTD). These provide important concerns, which will be taken into consideration when the Change Laboratories commence. Kerosuo, Engeström and Kajamaa (2010, p. 112) explain Change Laboratories as 'a research-assisted environment of change in which participants can re-design their work activity and organisation by creating new models, tools and practices with the aid of researcher-interventionists'.

A brief overview of cultural-historical activity theory

For readers not familiar with CHAT, we will provide a short overview. Cultural-historical activity theory as a research lens had its rhizomic development from Vygotsky's (1978) social constructivism. First-generation CHAT focused on how 'tools' (among others, language) are used to scaffold learning: how the learner (as 'subject' in the activity system) utilises tools to obtain the 'object' (the learning goals). Second-generation CHAT expanded the activity system, to also consider the 'rules' at play in an activity system, the 'community' involved and the 'division of labour'. Rules include policies and legislation that might influence learning, as well as the curriculum. The community involves all stakeholders in the activity system (e.g. in a school context, teachers, learners, parents, the school governing body and principal) and the Department of Basic Education (DBE) (e.g. the subject advisor). The division of labour refers to the different roles of the 'subject'.

For example, if the 'subject' in the activity system is a teacher, the division of labour would refer to the teacher as a facilitator of learning, assessor, inclusive practitioner, an agent of change, etc. This CHAT analysis could provide insight into complex situations (activity systems), where cultural and historical factors are at play (Mentz & De Beer 2019a). Engeström (2008) emphasises that CHAT is best used in the context of two interdependent activity systems as the minimal unit of analysis. For example, two activity systems are at play in the science classroom: in one activity system, the subject is the teacher, and in another activity system, the subject is the learner. This is a third-generation CHAT. Often, the two objects of the two activity systems are not aligned – a phenomenon known as the 'contradiction of control' (McNeil 2013). Fourth-generation CHAT is nascent research, where several (not just two) activity systems are considered in a particular complex historical-cultural context. In the context of this chapter, it would look at the affordances of Change Laboratories.

■ The effectiveness of teacher professional development programmes, with special reference to the Western Cape province

Based on a research study in the Gauteng province in South Africa, Mestry, Hendricks and Bisschoff (2009) identified a number of factors that negatively impact teacher professional development: not taking the real needs of teachers into consideration; competing initiatives or the involvement of several training institutions, which drain resources and dilute professional development efforts; the absence of a coherent and integrated professional development plan; teachers not being self-directed; and teachers not being intrinsically motivated.

Ajani (2020) studied teachers' perceptions of professional development programmes in the KwaZulu-Natal province of South Africa. The findings were that teachers disapproved of the inadequate and irregular training and workshops; the interventions did not address teachers' classroom needs, teachers expressed the wish that they should be consulted when planning teacher professional development programmes; and teachers also asked for adequate monitoring and follow-up sessions.

Some CPTD programmes are more effective than others. Mokhele and Jita (2010) showed that teachers generally valued the Mpumalanga Secondary Science Initiative. Teachers appreciated the cascade model and that it was accompanied by regular workshops for heads of departments. Teachers also valued the fact that they worked in clusters/networks; that they were afforded the opportunity to share knowledge and expertise in small groups; and that they were supported by university-based subject experts. Teachers indicated that their participation in the CPTD led to personal transformation and growth.

The context of this chapter is CPTD in the Western Cape province. There are eight educational districts in the Western Cape province, and Johns and Sosibo (2019) studied teachers' perceptions of CPTD in two of the districts. Their study highlighted two main themes.

Teachers displayed negative attitudes towards continuous professional teacher development and showed a lack of motivation

The sampled teachers expressed feelings of demotivation, distrust and frustration with the CPTD policy and its implementation. One of the participants indicated that they '[...] feel belittled as professionals. The WCED distrust teachers, as we are just a PERSAL number to the department' (Johns & Sosibo 2019, p. 139). Continuous professional teacher development was described as a 'hit-and-miss' exercise that results in negative teacher attitudes. This highlights the bureaucratic mode of organisation, as explained by Metha (2013).

A culture of compliance and coercion

Participating principals and teachers felt that the CPTD policy was compliance-driven, and its implementation forced upon them. 'CPTD became a compliance and superficial activity rather than a developmental and purpose-driven exercise' (Johns & Sosibo 2019, p. 141).

Unfortunately, CPTD in the Western Cape province (as in other provinces in South Africa as well) often fall short of the description provided by Lee (2005):

> Overall, for the best outcomes, a professional development programme should have an appropriate level of challenge and support, provide activities demonstrating new ways to teach and learn, build internal capacity, use a team approach, provide time for reflection and evaluate the effectiveness and impact of its activities. (p. 47)

Continuous professional teacher development in the Western Cape province: Concerns raised by a Senior Educational Specialist (Curriculum: Further Education and Training)

For Change Laboratories to be effective, the voices of all stakeholders should be heard. This is nascent research, with only inputs from the UWC and WCED thus far. Three important themes emerged from a reflection by a Senior Education Specialist in the WCED. These autobiographical accounts (which Bligh & Flood 2015; Engeström 2008 refer to as 'mirror-data') are important to expansive learning actions (expansive learning is discussed later in the chapter). These are important sentiments that should feed into the Change Laboratories.

The bureaucratic system often leads to a washout effect of newly acquired knowledge and skills

The educational department is a bureaucratic organisation, with multiple cogs turning, each with its own purpose, and rules and procedures that can only obtained by experience or guidance from other officials. The organogram of the WCED has the Head of Department, with four Deputy Director Generals (Educational Planning, Curriculum and Assessment Management, Institution Development and Coordination, and Corporate Services). Each one of these Deputy Director Generals has two Chief Directors branching out from them, with several Directorates branched out of each Chief Directorate. This is the structure from Head Office. Schools all fall inside a circuit, which is managed by Circuit Managers, and the circuits form part of a district, which is decentralised to be in closer proximity to the schools.

Teachers have access to different avenues that provide PTD. The first point of contact will be the school. Schools have a mandate to upskill their staff. These PTD sessions facilitated by schools are more generic and not subject specific. Furthermore, each province has a Centre for Teacher Professional Development; in the Western Cape province, this Centre is the Cape Teaching and Leadership Institute (CTLI). The CTLI is a sub-directorate of the Chief Directorate of Curriculum Management and Teacher Development. The CTLI is responsible for in-service training of teachers, school leaders and curriculum officials of the WCED. The CTLI is dedicated to the continuous development and support of teachers to address gaps in their content knowledge and improve pedagogical practices.

The in-house courses, which are developed by CTLI, target 'high enrolment, low performing' subjects, such as Mathematics and Life Sciences. These are non-accredited courses. The course developers for the in-house courses work very closely with officials from the WCED, mostly with the Senior Curriculum Planners (SCPs). The role of the SCPs is to ensure quality assurance in the content development of these target-specific courses. The CTLI also offers accredited courses in collaboration with the University of Cape Town (UCT) and Stellenbosch University (SU). Teachers can do an Advance Certificate in Education, which is aimed at teachers who are teaching 'out-of-phase'. This will upskill these teachers and enable them to apply for positions outside their current teaching phase.

Anecdotal findings as per conversation with the FET Coordinator at CTLI suggest that teachers do register for offerings at the CTLI, but the biggest concern is the completion of courses. The coordinator indicated that the current average completion rate is between 70% and 85%. On average, they would like to improve to a 100% completion rate. The CTLI in most cases offers a Certificate of Completion, which serves as an incentive for teachers to adhere to their commitment.

The next place where teachers get access to PTD is from their subject advisors. The subject advisors will provide specific content and assessment-related PTD for the teachers. Additionally, teachers can do PTD through higher educational institutions (HEIs). The last option usually has cost implications that the teachers need to pay for themselves, whereas the other options are funded by the DBE. HEIs should be approached to assist with PTD. Higher educational institutions are responsible for the initial training of teachers, but they are seldom used for PTD. A small percentage of teachers obtain postgraduate degrees or certificates. The introduction of short learning programmes (SLP) can assist teachers with PTD, according to their needs and not a predefined list that was generated in a bureaucratic meeting. With in-service teachers engaging with HEIs, there will be a natural feedback loop between the HEIs and the WCED. This feedback loop can be used by the HEIs to determine any shortcomings in their initial degrees, and they will be able to amend their degrees to provide teachers with the necessary skills to be competent teachers.

Teachers can easily become stuck in a comfort zone. During the first year of teaching, most novice teachers struggle with content knowledge or the transfer of this content knowledge to the learners. They try innovative ways of teaching, attempting to make teaching more engaging for the learners, but then deadlines approach and pressure begins to mount on completing specific prescribed content over a specified time period. When the pressure increases, teachers fall back to the known way of teaching, or what they experienced when they were at school, normally lecture style. There is not enough PTD provided to the teachers on innovative teaching strategies. By changing the way that content is presented to the learners, the learners can be more receptive to learning.

Research has shown that this ‘washout effect’ (Zeichner & Tabachnick 1981) results in reformed teaching being compromised. Science teachers often complete PTD interventions with great enthusiasm, but because of bureaucratic factors, they fall back to old practices in the post-intervention classroom (Petersen, Golightly & Dudu 2019).

A dualistic focus on teacher professional development

There are two broad categories of in-service teachers that I as a senior educational specialist encounter while advising teachers (personal reflection by the third author). The first category of teachers are the ones who have excellent pedagogical content knowledge and strive to improve their knowledge of the subject. The other category of teachers are the teachers who have limited pedagogical content knowledge in the subject(s) they teach. These teachers are compliant with all the necessary policies, follow annual teaching plans to the letter and have all the relevant documents and assessments in their teacher files. When it comes to the moderation of these teachers' work, it will be found that there is no consistent allocation of marks, and the interpretation of the learners' work is not done correctly. The teachers are bound by the memo of the assessments, and they do not interpret beyond the basic items found in the memo. In the classes of these teachers, they tend to use a lecture style of teaching, where content is presented to the learners. There is limited to no engagement with the content between the teachers and the learners. This creates a vacuum in how learning takes place in the classroom. The learning that takes place in these classrooms is based on rote learning, focusing on factual recall, and no higher cognitive learning is achieved.

On the other hand, the first category of teachers (with advanced pedagogical content knowledge [PCK]) embrace different teaching practices that are more learner centred, and not teacher centred, to enhance learning. They use teaching strategies such as problem-based learning, gamification and a flipped classroom approach. The teachers who are using these strategies are in the minority. We also encounter some teachers who have excellent results in the Grade 12 exit examination, the NSC, who only 'teach' towards the NSC examination. These teachers in fact only coach their learners towards what can be expected in the NSC examinations, and then, the learners rote learn what to write at the specific sections of the papers and achieve good marks for these papers. In this case, learning did not take place. The learners are only efficient in writing the papers, but cannot apply the content that they have 'learnt' in any other context.

This dualism creates a challenge when conducting teacher professional development interventions, because of the different knowledge and skill sets of the participating teachers.

Lack of teachers setting professional development learning goals for themselves as self-directed learners

In an informal survey given to the teachers of the subject that I support, the question prompted to the teachers was: ‘Please indicate any support that you require’ (Reflections by the third author). There were 48 responses to the survey, and of those 48, only 19 added a response to this question. Twelve of those responses indicated that they did not need any support, two teachers requested past papers and resources, and the other were non-specific responses.

Most of the teachers do not indicate their specific needs for PTD. This can be the result of a busy schedule at the school, where the teachers are expected to participate in extramural activities, teachers get access to PTD at the school level or teachers do not want to recognise to their subject advisor that they have a gap in their pedagogical content knowledge. Teachers are also reluctant to indicate specific PTD needs, as they will be required to participate in the PTD over a weekend or school holiday, which is a time they do not want to sacrifice. There are also some of the teachers who do not subscribe to the idea of PTD. They are of the opinion that they did study for a degree, and they have been adequately prepared for teaching, or that they have been teaching for such a long time, and they know how to teach. These teachers are seldom seen at workshops or any PTD sessions.

The above reflection supports the statement of Mehta (2013) that bureaucracy in the education system undermines the development of teacher agency.

Change Laboratories and how it could result in transformed teaching and learning

Cultural-historical activity theory assumes collective, object-oriented and culturally mediated human activity as the unit of analysis where activities are oriented to and driven by goals and objects. Recently, the focus has been on multiple interacting activity systems and boundary crossing between shared objects in these activity systems. An activity can be seen ‘as an active engagement of a person with his or her environment (including social contexts)’ (Mironenko & Sorokin 2022, p. 1057). This study is based on Engeström’s (2011:599) belief that ‘(h)uman learning takes place within and between complex, continuously changing activity systems’. An activity system indicates the embeddedness of people within a socio-cultural context in which they interact. Within an activity system, there is a ‘subject’ and an outcome or goal as an 'object' that motivates the existence of an activity (Igira & Gregory 2009, p. 436). Mediated artefacts such as 'tools' and 'rules', 'division of labour' and the 'community', used by the subject, all contribute to facilitate the realisation of the object within an activity system (Mentz & De Beer 2019b). Mediated artefacts assist the subject to transform the object (Igira & Gregory 2009).

Expansive learning is a learning theory that focuses on innovation and change in social practices (Morselli 2018), in which participants constantly re-imagine their activity and in so doing expand the object of the activity (Engeström 2015). Within expansive learning, contradictions play a significant role. Contradictions are 'historically accumulating structural tensions within and between activity systems' (Engeström 2011, p. 609). According to Engeström (2011), systemic contradictions drive change as they not only lead to doubts, dilemmas and even conflict but also contribute to innovative ways to change the activity. During expansive learning opportunities, a rediscovery of activities that differ from the normal thinking patterns can empower practitioners. With expansive learning, participants move from the abstract to the concrete in their strive towards collective concept formation (Morselli 2018). They 'work together to re-imagine the object of their activity' (Bligh & Flood 2015) to successfully solve tensions or contradictions in an activity system (Engeström 2008). Engeström (1987) suggested different stages in expansive learning, starting with questioning, and progressing to criticising, analysing, modelling, examining, implementing, reflecting and ending with consolidation. Stages in an expansive learning cycle can briefly be summarised as (Engeström 1987; Englund & Price 2018; Igira & Gregory 2009):

1. engagement in an activity system by examining and questioning current practices
2. identification and analysis of systemic tensions and contradictions between and within activity systems
3. modelling of new approaches to solve problems identified
4. examination, testing and evaluation of the suggested model in actual settings
5. revision and implementation of new models
6. evaluation and reflection on new practice
7. consolidation and generalisation.

Change Laboratories, guided by activity theory (Bligh & Flood 2015) and based on CHAT principles (Botha 2017), can trigger cycles of expansive learning and serve as a formative intervention-research methodology (Bligh & Flood 2015) where close emotional involvement of all stakeholders is required (Morselli 2018). The purpose of a Change Laboratory is to systematically analyse problems faced in the workplace and suggest, develop and implement new models to solve these problems (Igira & Gregory 2009). A key outcome of formative interventions like Change Laboratories according to Engeström (2011) is that participants gain agency. Agency in this context can be defined as collectively 'striving towards the common good' (Blanchet-Cohen & Reilly 2017; Boyte & Finders 2016; Sannino 2022, p. 9). 'A Change Laboratory is typically conducted in an activity system that is facing a major transformation' (Engeström 2011, p. 612). Participants in a Change Laboratory can take charge of the process, 'critique existing aspects of their activity system, model and restructure them and then experiment with and reflect upon the new practices or tools, instigating further cycles of revision and innovation as required' (Botha 2017, p. 84). They must deal with contradictory and problematic objects within different activity systems which can be expanded to build new concepts. In general, Change Laboratories focus on problems of local practice (which might also be indicative of broader systemic inconsistencies), moving from the abstract to the concrete in a cyclic expansive learning process, and trying to intervene and develop at the same time.

According to Virkkunen (2006), double stimulation in a Change Laboratory is an important aspect of building practitioners' willingness to transform their activity system. Double stimulation can be defined as the development of a collective transformative agency during which the participants can break away from the normal situation to collectively implement a new model to accomplish systemic change (Haapasaari, Engeström & Kerosuo 2016). In so doing, participants 're-imagine the object of the activity' (Bligh & Flood 2015, p. 142) and can change and transform their circumstances or current practices. During this process, they develop collective transformative agencies, while searching for new models or practices (Engeström & Sannino 2016). Transformative agency within a Change Laboratory can include questioning, rejecting, criticising and opposing existing activity systems which can result in commitment to change and suggestions for concrete actions (Haapasaari et al. 2016). In a study done by Englund and Price (2018) while implementing Change Laboratories, they found that transformative agency emerges when teachers are given the opportunity to collaboratively analyse and restructure their practice.

By engaging all stakeholders in the Western Cape in such a Change Laboratory, the WCED will benefit from hearing the unfiltered voices of teachers. The acknowledgement of 'being heard' will enhance teacher agency, which could result in reformed teaching practices.

Change Laboratories: A nascent research field

Change Laboratories is a nascent research field, and limited work has been done in this arena in South Africa. Winberg, Garraway and Wright (2023) indicate that a systematic review has identified 22 studies in South Africa (up to November 2023) on Change Laboratories. However, these studies represent a mix of classic-, partial- and augmented Change Laboratories. The authors emphasise that 'all Change Laboratories are adaptations. As Virkkunen and Newnham (2013) point out, the Change Laboratory is not a standardised method that could be followed as if following an algorithm' (Winberg et al. 2023, p. 214). The 22 studies were located in the fields of agriculture, community development, health care, education and industrial settings. Much of the work done was in an environmental and sustainability education context. Lotz-Sisitka et al. (2017) studied transformative agency in community-based learning for sustainability. Lindley and Lotz-Sisitka (2019) investigated social learning and reflexive action in an organisation responding to wetland degradation. Garraway and Christopher (2020) utilised Change Laboratories to explore the mentoring of emergency health care students (paramedics). Le Mottee (2020) used a Change Laboratory approach to explore gaps in the provision of early childhood care. Mbelani (2018) focused on in-service teacher development in terms of visual literacy. More relevant to this chapter is the work of Botha (2017), who conducted a Change Laboratory in a Cape Flats High School in Cape Town, in an attempt to address the challenges facing the school.

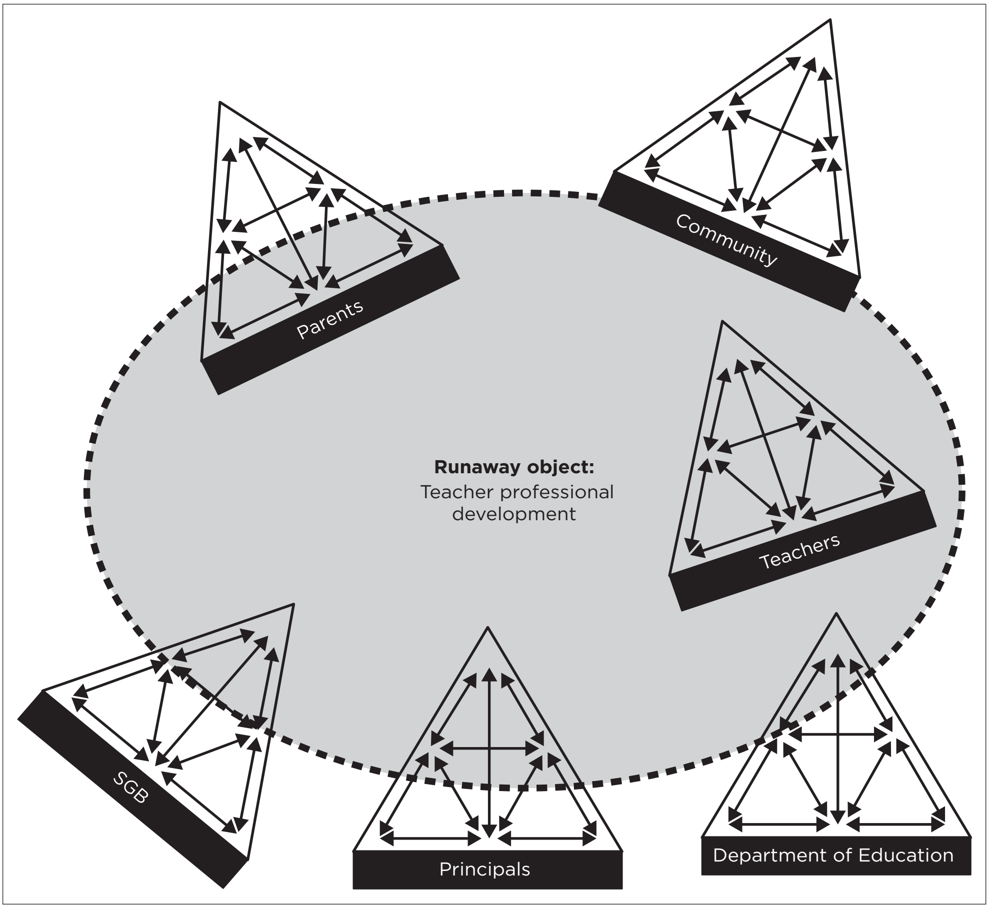
Fourth-generation cultural-historical activity theory as a research lens

Cultural-historical activity theory passed through three generations or phases and is based mainly on the work of Vygotsky (1978), Leontiev (1978), Luria (1976) and Engeström (2011). The theory is strongly rooted in social constructivism and can be used as a research lens. Cultural-historical activity theory as a research lens provides insight into the complexity of the object in relation to the subject, with the involvement of mediating tools, rules, division of labour and the community as part of an activity system. It emphasises external and internal factors that influence the object and outcome of the activity system (Mentz & De Beer 2020). The unit of analysis within third-generation CHAT moved to two or more activity systems with partially shared objects (Engeström 2011). In third-generation CHAT, the researcher can interpret data from different activity systems that are embedded in a specific cultural and historical context (Mentz & De Beer 2020). In fourth-generation CHAT, all stakeholders can be seen as separate activity systems. This is where Change Laboratories can be a helpful tool where contradictions as a source of change and development between different activity systems can result in expansive learning opportunities to come to a shared understanding of the object and a transformation of practice (Engeström 2011; Mentz & De Beer 2020). Boundary crossing between different activity systems is possible with fourth-generation CHAT. According to Akkerman and Bakker (2012, p. 132), boundaries carry learning potential as 'all Op involves boundaries' – boundaries in terms of identification, coordination, reflection and transformation (Akkerman & Bakker 2012). Akkerman and Bakker (2012, pp. 133, 153) argue that a boundary can be seen as socio-cultural differences leading to a discontinuity in action or interaction and 'boundary crossing refers to the ability to interact despite the sociocultural differences' and 'establishing continuity in a situation of sociocultural difference'.

In this project, the WCED and UWC, as key stakeholders, would like to work together with all stakeholders – school governing bodies (SGBs), principals, teachers, parents and teacher unions – in rethinking teacher professional development, through Change Laboratories as the vehicle. Lotz-Sisitka et al. (2017) see social learning as important for change-oriented learning and transformative agency. The latter authors state, '(s)ocial learning reflects changes in activity and practice at different levels in a system: at the level of the individual (e.g. cognitive, attitudinal and behavioural changes); at the level of community practice; and at the level of the wider system (e.g. changes in governance and management systems)' (Lotz-Sisitka et al. 2017, pp. 899–900). So far, as reported in this concept chapter, autobiographical accounts of practice (Bligh & Flood 2015) have been collected. There has also been engagement with corporate partners, to assist with the funding for a project of such magnitude. Higher Educational Institutions will offer teacher professional development programmes to science teachers without any costs to the teachers or to the WCED, because of corporate investment.

A Change Laboratory project for teacher professional development in the Western Cape province

Change Laboratories, embracing boundary crossing and the possibilities of expansive learning, can result in systemic change among different socio-cultural activity systems. The 'runaway object' (Engeström 2008) can be



Source: Fourth-generation CHAT, as conceptualised by Engeström (2008); author's own interpretation.
Key: SGB, school governing body.

FIGURE 3.1: A Change Laboratory approach to teacher professional development.

clearly defined by the different stakeholders, and mutual engagement might result in the development and implementation of a CPTD programme that would result in systemic change (see Figure 3.1).

Table 3.2 highlights provisional concerns and inputs from two of the stakeholders – the WCED and the UWC as HEIs – that will be presented at the Change Laboratories.

TABLE 3.2: Concerns and suggestions by the Western Cape Education Department and University of the Western Cape (as higher education institutions) which should feed into the Change Laboratories.

Concerns and suggestions raised by the WCED in terms of CPTD	Concerns and suggestions raised by the UWC in terms of CPTD
Acknowledging the need to break the cycle of bureaucracy and make teacher agency the focus of CPTD programmes.	Self-directed learning should form the basis of CPTD. Teachers' needs and learning goals should be supported during the programme, and teachers should take responsibility for their professional learning.
The above also implies addressing systemic tensions that lead to the 'washout' effect of newly acquired knowledge and skills – for example, the annual teaching plan (ATP) which creates much pressure and anxiety among teachers and often corrodes agency.	CPTD should be of sufficient duration, and teachers should be supported throughout the programme – among others, online support and creating supportive communities of practice (De Beer & Kriek 2021). For online support, a community of inquiry framework (Fiock 2020) is needed, building on cognitive presence, social presence and teaching presence. Although ATPs have merit, they should not erode reformed teaching practices in the post-intervention classroom.
Confirming the need to work with HEIs in addressing the professional development needs of teachers. However, consultation and alignment with in-house teacher professional development agencies, such as the CTLI, are needed. A more integrated approach to CPTD is needed.	Close liaison is needed with the WCED and working with the subject advisors and school management team. Change Laboratories could facilitate such a systemic approach to CPTD. It is important that there is support and encouragement for teachers to utilise engaging pedagogies.
Teacher professional development programmes should address the real needs of teachers.	CPTD programmes should emphasise approaches and pedagogies, such as problem-based learning and cooperative learning, that enhance self-directed learning. It is essential that CPTD programmes use teachers' real needs as departure and assist them to, as self-directed learners, obtain their learning goals.
A differentiated approach is needed to cater for both teachers with nuanced pedagogical content knowledge (PCK) and professional development of teachers with under-developed PCK.	Teachers should be supported to become more critical reflective practitioners. CPTD programmes should therefore emphasise the role of reflection (as well as classroom action research), as tools for professional development (Gravett & De Beer 2015).
	In order to provide this CPTD without costs for the WCED or the teachers, partnerships with the private sector and funders are needed. This would also catapult the provision of teaching and learning resources, especially for under-resourced schools.

Key: HEI, higher education institution; WCED, Western Cape Education Department; CPTD, continuous professional teacher development; UWC, University of Western Cape; ATP, annual teaching plan; CTLI, Cape Teaching and Leadership Institute.

Conclusion

Change Laboratories is a pragmatic way to address Bronfenbrenner's (1977) comment that:

> [*R*]esearch on the ecology of human development should include experiments involving the innovative restructuring of prevailing ecological systems in ways that depart from existing institutional ideologies and structures by redefining goals, roles and activities and providing interconnections between systems previously isolated from each other. (p. 528)

Bronfenbrenner emphasised that transformation cannot be controlled but should be influenced and shaped. Schein (1996, p. 60) observed that 'all forms of learning and change start with some form of dissatisfaction or frustration generated by data that disconfirm our expectations or hope'. Change Laboratories hold affordances to impact systemic change. As Botha (2017) shows:

> [*T*]hrough a collective cycle of expansive learning the participants critique existing aspects of their activity system, model and restructure them and then experiment with and reflect upon the new practices or tools, instigating further cycles of revision and innovation as required. (p. 84)

In this chapter, limited autobiographical data and literature findings provided a picture of dissatisfaction with CPTD programmes in the Western Cape province that do not lead to reformed teaching practices in post-intervention classrooms. By implementing Change Laboratories in the Western Cape province, these concerns might be addressed. Despite the fact that the shift from a Science, Technology, Engineering, Mathematics (STEM) to a STEAM approach happens at a glacial pace, such a change, in order to be successful, is dependent on effective CPTD. Change Laboratories holds promise to ensure more successful CPTD.

Chapter 4

Promoting the heuristic in STEAME teacher education: Facilitating meaningful learning

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Abstract

As we navigate the Fourth Industrial Revolution in education, we need to re-imagine teaching and learning approaches, strategies and methodologies for Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) subjects to ensure that we reach our societal goals in this

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technology-driven context. Disruptions in traditional teaching approaches are argued for in this chapter where a heuristic approach to teaching is suggested. We draw on Piaget's equilibrium theory, which suggests that inducing cognitive conflict prompts individuals to either assimilate or accommodate new information, leading to the 'AhA-moment' and the restoration of equilibrium. This approach is envisioned for future-proofing STEAME education. To support this endeavour, the discussion and recommendations focus on how professional development initiatives can facilitate this process.

Introduction

Venturing into Education 4.0 (Fourth Industrial Revolution education), it becomes imperative to re-imagine teaching and learning approaches, strategies and methodologies to future-proof quality education specifically in scarce skilled disciplines such as Science, Technology, Engineering and Mathematics (STEM). In recent decades, traditional or conventional education methods were still forefronted in the endeavour to reach the set curriculum outcomes because of decreased teaching time, an overloaded curriculum and increased workload, an increase in class size and all that it implies, and a lack of administrative support contributing to workload increase for teachers among other (Chisholm et al. 2005).

Traditional, or ostensive, teaching methods are mostly used where educators play a central role in conveying prescribed content knowledge in the classroom. This approach is referred to as teacher-centredness and emphasises the transmission of information from educator to student. The educator is thus seen as the primary source of knowledge and the main facilitator of learning. Traditional ways of teaching will typically include passive teaching activities such as presentations or lectures, demonstrations and rote memorisation, and focus on explicitly prescribed examples, models or visual aids to convey information effectively. Students are thus expected to absorb and memorise the pre-scribed subject content presented to them and are often evaluated based on their ability to recall this presented information during examinations, tests and quizzes.

According to Hanushek and Woessmann (2015), societal needs and skills have changed over time, claiming that increasing disparities in knowledge and skills among populations, nations and economies have led to increasing inequalities in a technology-driven society, albeit education in the 21st century continues to evolve, bringing forth innovative and effective teaching and learning approaches and methodologies in an attempt to curb disparity and enhance education for all as per the Sustainable Development Goals (SDGs).[15]

However, according to the United Nations, the sustainable development plan has always included education for all people as a key component. Sustainable Development Goal number 4 highlights inclusive, equitable and quality education ensuring everybody has access to high-quality, inclusive education and encourages possibilities for lifelong learning. To achieve SDG 4, all stakeholders in education need to take action in disrupting current teaching and learning methodologies and approaches and invest in new, fit-for-purpose education in this new era.

In the chapter, we thus argue for a disruption in traditional teaching approaches and ostensiveness to afford fresh approaches to teaching and learning to emerge in the new, unknown technology era that the upcoming generations are facing. It calls for a heuristic approach to teaching as professed in the early 1900s[16] by Professor H. E. Armstrong (1848–1937). The word 'heuristic' is derived from the Greek word 'heurisca', which means 'to find out'. The heuristic generally refers to any strategy or method that encourages problem-solving, self-learning and self-discovery. The heuristic approach to teaching is therefore a method of teaching that places a strong emphasis on the use of experience-based learning, inquiry-based learning and problem-solving that strongly reflects self-directed learning (SDL). Self-directed learning shows potential in facilitating students' acquisition and mastery of 21st-century skills within Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) contexts (Mercado 2024). This approach aligns with the essential 4Cs of 21st-century learning skills. The 4Cs, namely, Critical Thinking, Creative Thinking, Collaboration and Communication, are the essential higher-order thinking skills (HOTS) that are crucial in developing today's students as tomorrow's leaders. Higher-order thinking skills should be engaged continuously to ensure up-to-date informed students. It needs to be applied in the teaching and learning process to meet the demands of 21st-century learning. Students who were exposed to the 4Cs have demonstrated that they are successful through problem-solving and SDL (Chiruguru 2020). The 4Cs of learning skills therefore lean strongly towards the heuristic fit for STEAME.

15. https://sdgs.un.org/topics/education. Accessed 29 Aug 2023

16. https://testbook.com/question-answer/who-introduced-the-heuristic-method-for-teaching-s--5fb92a41c8e50176c3053d17 (accessed 15 July 2023).

Background

The heuristic method of teaching offers many potential benefits to students but could also include some disadvantages. Students may benefit greatly from the heuristic approach in that they are more engaged in learning when educators encourage/facilitate active investigation and problem-solving that leads to a deeper understanding of the subject content material and a greater sense of ownership of their own learning through facilitation. Additionally, the heuristic approach fosters creativity and critical thinking skills, increases the cognitive abilities that are essential in the sustainable development of knowledge and skills in global societies (Hanushek & Woessmann 2015), and prepares students for future professions (some still unknown) and careers in the upcoming technology-inspired workforce and marketplace of this era.

The advantages and disadvantages of the heuristic approach can vary depending on the context and specific implementation of the heuristic teaching method.[17] It promotes efficient problem-solving skills whereby students can simplify complex tasks or information, leading to faster and more effective decision-making. It encourages creative and flexible thinking by breaking away from rigid rules for teaching and learning, fostering an exploratory and open-minded approach to problem-solving. Furthermore, it promotes hands-on experiential learning through trial and error that encourages active engagement and exploration, allowing students to discover patterns, strategies and insights on their own and allowing active participation in the problem-solving processes. Some disadvantages of the heuristic approach could include non-suitability for all student learning styles because it could rely on specific prior knowledge and skills in specific contexts, covering a large amount of material, and assessing and evaluating student progress could be challenging. It could become time consuming in planning and preparation, and the method may not align well with standardised testing and assessment methods. Successful implementation would require high levels of student engagement and motivation and effectively trained educators.

By incorporating the heuristic approach into Education 4.0 teaching and learning praxis, educators should foster critical and creative thinking skills or HOTS, problem-solving abilities, collaboration and adaptability in students, preparing them for real-world challenges and lifelong learning.

Keeping a balance, an equilibrium, in the ostensive-heuristic continuum asks for transitions between ostensive and heuristic that

17. (https://zonofeducation.com/heuristic-method-of-teaching/ (accessed 15 July 2023)

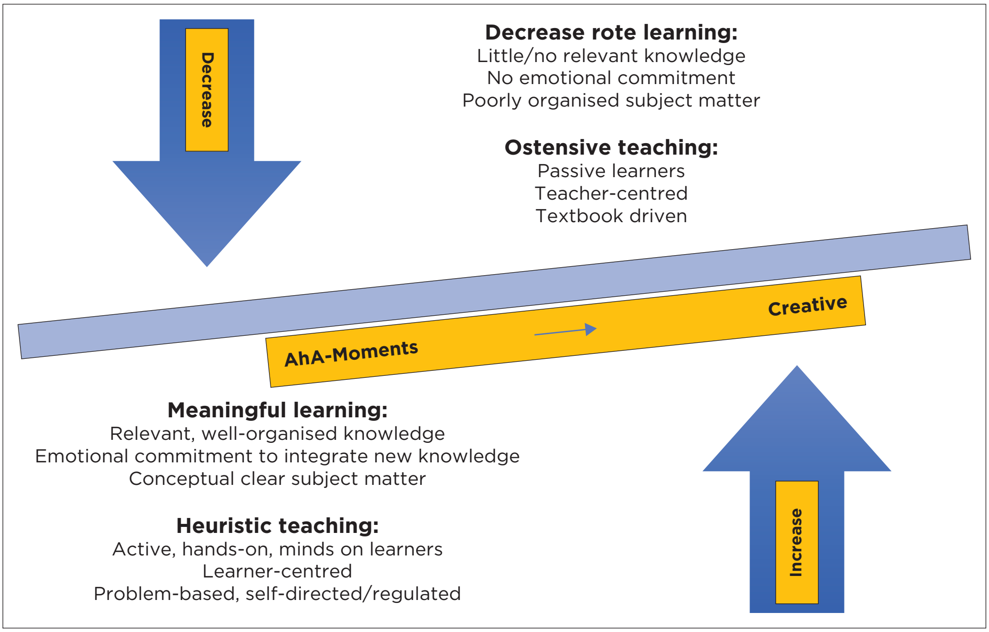
speak to Piaget's equilibrium theory, referring to an ongoing cognitive developmental process, refining and transforming mental structures. As students encounter new objects and experiences, they subconsciously attempt to fit them into their existing knowledge framework (Cohen & Kim 1999).

Both ostensive and heuristic approaches to teaching and learning, embedded in the equilibrium theory, highlight the importance of engaging students actively in the learning process, providing clear demonstrations and problem-solving strategies and promoting the resolution of cognitive conflicts. By integrating these approaches, educators can create a conducive learning environment that fosters optimal learning outcomes and cognitive development for future generations – reaching the AhA-moments. 'A sudden comprehension that solves a problem, reinterprets a situation, explains a joke, or resolves an ambiguous percept is called an insight (i.e. the "Aha-moment")' (Kounios & Beeman 2009, p. 3).

When AhA-moments are reached, meaningful learning takes place which in essence relates to the heuristic and SDL as students take responsibility for applying what they already know to what they are seeking to know. Ausubel's (2012) cognitive theory of meaningful learning comes into play here. His meaningful learning theory was founded on the idea that learning and remembering are the results of an active, integrative, interactional process (heuristic) where students relate new information to relevant concepts they already know, emphasising the role of prior knowledge in learning and learning for understanding (Ausubel 2012). This opposes the rote verbal learning (ostensive). Therefore, to address and facilitate the achievement of AhA-moments, we should integrate the rote-meaningful learning continuum[18] with the ostensive-heuristic continuum as depicted in an adapted diagram (Figure 4.1). Decreasing traditional rote learning resulted from ostensive teaching approaches will tip the scale of the continuum, and new modern, heuristic approaches to teaching will increase meaningful learning that is imperative in shaping the new generations for future professions specifically pertaining to the STEAME education milieu.

The balancing act between the ostensive and heuristic, or the rote-meaningful learning continuum within Piaget's equilibrium theory, could potentially cause the needed cognitive conflict to address the requirements for STEAME education in the 21st century.

18. See https://dl.icdst.org/pdfs/files1/7e9bd5801e72bf80a66e4b3fd0b06c50.pdf (accessed 17 August 2023).



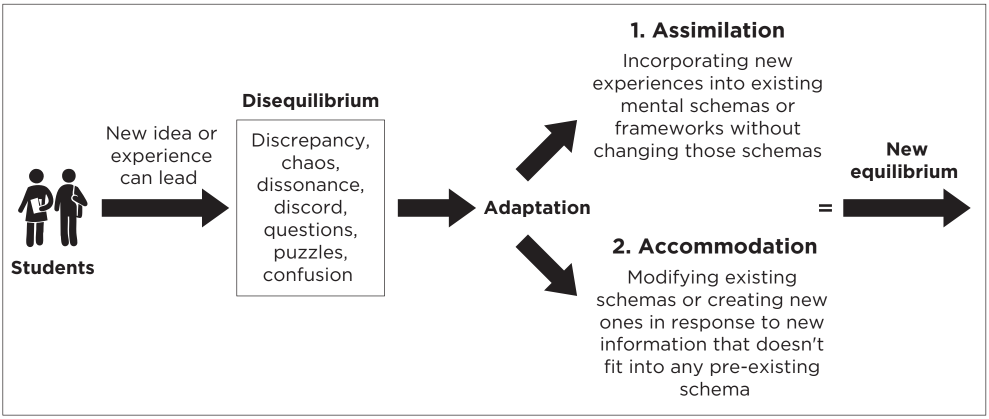
Source: Adapted and constructed from Ausubel's (2012) theory of meaningful learning and Zone of Education website (footnote 4).

FIGURE 4.1: Rote-meaningful learning integrated ostensive-heuristic teaching continuum.

■ Piaget's equilibration theory

Jean Piaget (1952), the renowned Swiss developmental psychologist, made significant contributions to our understanding of child development through his theory of cognitive development. Central to this theory is the concept of equilibration, which Piaget proposed as the primary mechanism propelling the progression of cognitive development.

An essential aspect of learning is the student's prior knowledge, which encompasses all the knowledge they bring into a learning environment (Figure 4.2). According to Ausubel (1968) and Duit (1999), this prior knowledge is the cornerstone of meaningful learning. From a constructivist perspective, learners actively construct their own knowledge, drawing upon their pre-existing conceptions when trying to interpret new information. In some instances, this prior knowledge aligns seamlessly with new information, forming a foundation for learning. In contrast, at other times, there might be incompatibilities between prior conceptions and new information, necessitating a conceptual change (Desmet, Gregore & Mussolin 2010).



Source: Adapted from Govender (2013).

FIGURE 4.2: Piaget's equilibration theory – Part 1.

As depicted in Piaget's equilibration theory (Figure 4.2), assimilation and accommodation are two processes of adaptation that could restore equilibrium (Berger 2004; Piaget 1977, 1985).

Assimilation involves integrating new experiences into existing mental frameworks without any changes to these schemas. For example, students often face cognitive dissonance when they encounter unfamiliar situations that challenge their current understanding. They predict outcomes based on their prior knowledge. When these predictions align with reality, the new information is easily assimilated. However, contradictions or discrepancies can lead to confusion or anxiety, as noted by Sutopo and Waldrip (2014).

Accommodation, on the other hand, entails altering existing schemas or forming new ones when new information does not align with current schemas (Hanfstingl et al. 2021). If this new experience and information do not fit into the existing schema, misconceptions can arise. To address this, educators, as suggested by Dahlan and Rahayati (2014), can utilise scaffolding techniques, guiding students to reassess and identify misconceptions.

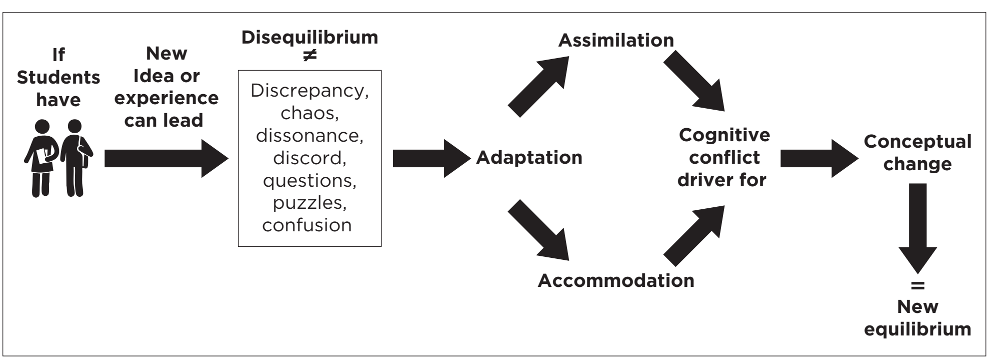
Equilibration is the act of balancing assimilation and accommodation to achieve a consistent understanding of the world. Piaget theorised that cognitive development unfolds in stages: sensorimotor, preoperational, concrete operational and formal operational. With each stage, cognitive structures evolve, becoming more intricate and versatile. Equilibration acts as the catalyst propelling learners from one stage to the next. However, disequilibrium is a state experienced when there's a mismatch between a person's current understanding and new information or experiences. This cognitive conflict or imbalance prompts the person to either assimilate or accommodate the new information, restoring equilibrium.

This approach encourages learners to re-evaluate, scrutinise and pinpoint the root causes of their misconceptions. Such introspection prompts learners to adjust their understanding, fostering a transition towards a more accommodative knowledge framework. This process of resolving the disarray and attaining a balanced understanding is termed equilibration, as described by Swan, Wake and Joubert (2006).

Cognitive conflict and conceptual change

Jean Piaget's equilibration theory, as depicted in Figure 4.3, is pivotal for understanding cognitive conflict and conceptual change. According to this theory, cognitive conflict emerges when there is a misalignment between a person's existing understanding and newly encountered information or experiences (Block 1982). This state of disequilibrium brings about tension and discomfort, urging the person towards resolution.

Cognitive conflict, which can be viewed in Figure 4.3, serves as the primary catalyst for conceptual change. It indicates a psychological discrepancy between one's established cognitive structure (or schema) and fresh information or between multiple cognitive structures. This concept was largely inspired by Piaget's theory of equilibration, which expounds on how assimilation and accommodation function harmoniously to restore mental equilibrium when thrown off balance. Such disequilibrium, which Piaget often labelled as cognitive conflict, can be instigated by providing learners with an opportunity to recognise contradictions or inconsistencies in their conceptions, as highlighted by various studies and



Source: Adapted from Govender (2013).

FIGURE 4.3: Piaget's equilibration theory – Part 2.

researchers such as Zaslavsky et al. (2010), Lee et al. (2003) and Buchs et al. (2004). Strategically employed counter-examples can be potent tools in this context.

Research has birthed various terminologies to describe cognitive conflict, contingent on the research focus or epistemologies. Festinger (1957), for instance, coined the term ‘cognitive dissonance’ – a concept further elaborated by Zaslavsky (2005) as the unease brought about by logical inconsistencies, pushing individuals to modify their beliefs to better align with reality. Meanwhile, Berlyne (1960), as referenced in Zaslavsky (2005), introduced the term ‘conceptual conflict’ in his theory, emphasising the paramount role of cognitive conflict in knowledge creation and acquisition. The ‘cognitive conflict’ approach to conceptual change has been extensively applied in diverse educational settings. To navigate this cognitive conflict, learners need to undergo a conceptual change, either by assimilating the new information into their existing schema without major alterations or by accommodating, adjusting or creating new schemas to incorporate the new information.

Posner et al. (1982) developed a model to elucidate conceptual change, incorporating Piaget’s ideas of disequilibration and accommodation. Their model highlighted two primary components: the prerequisite conditions for accommodation and a person’s conceptual ecology, which refers to the existing conceptions a learner possesses. This conceptual ecology becomes the immediate reference framework students use to interpret new information or experiences. Furthermore, Posner et al. (1982) identified certain conditions that must be met for accommodation to occur and subsequently prompt conceptual change. When these conditions are met, learners can assimilate or accommodate new concepts, as elaborated by researchers such as Posner et al. (1982), Strike and Posner (1985) and Hewson and Thorley (1989). However, if new concepts make sense but contradict existing ones, a conflict ensues. This conflict hinders the acceptance of new ideas, necessitating the devaluation of the conflicting conception for the new one to gain prominence.

Despite its prominence, Posner et al.’s (1982) conceptual change theory has faced criticism for its excessive focus on rationality at the expense of affective and social considerations. Recognising these shortcomings, the theory underwent revisions to incorporate cognitive, affective, social and contextual factors, emphasising the interplay between old and new conceptions. Many other theoretical models, developed by scholars such as Carey (1985), DiSessa (1988, 1993), Brewer (1987), Vosniadou (1994) and Thagard (1992), also strive to explain conceptual change. While not all were crafted for classroom application, empirical studies tested their classroom feasibility.

Cognitive conflict strategies span multiple disciplines and have been instrumental in various educational journeys. Learners, while learning, often face scenarios that challenge their existing knowledge. In such instances, they might use prior knowledge to predict outcomes. When these predictions align with new experiences, assimilation occurs. However, discrepancies can lead to cognitive conflict, requiring interventions like scaffolding, as suggested by educators and researchers.

To gain a more profound appreciation of cognitive conflict and conceptual change, as conceptualised by Piaget's theory, it is useful to delve into practical, real-world examples. These instances not only exemplify the theoretical concepts but also demonstrate their tangible manifestations in everyday scenarios, aiding in a richer understanding of the learner's cognition.

Conservation tasks: A deep dive

Piaget's studies produced various intriguing experiments, and among the most enlightening is the conservation task (Stadtländer 2023). This experiment was tailored to probe into a child's cognitive development, particularly their grasp of quantity. During their early years, specifically the preoperational stage encompassing ages 2 to 7, children often derive their understanding of quantity based on an object's visual presentation rather than its intrinsic properties.

Consider this: A child is presented with two identical amounts of water in two glasses. The water from a short and wide glass is transferred to a tall and slender one. For a child within the preoperational age bracket, this transfer seemingly increases the water quantity. They are swayed by the augmented height of the water in the tall glass, overlooking the corresponding reduction in width.

However, the cognitive landscape shifts when the same child witnesses the water being poured back and forth between the glasses, underscoring the constant quantity. This revelation challenges their prior belief, pushing them into a state of cognitive conflict. As the child matures, advancing into the concrete operational stage (usually between ages 7 and 11), they evolve a refined understanding of conservation principles. This growth empowers them to discern that modifications in an object's appearance do not invariably equate to changes in its intrinsic quantity.

Deciphering the earth's shape

The realm of cognitive development is rife with captivating insights, one of which revolves around learners' perceptions of the Earth's shape

(Singh, Agrawal & Ghosh 2017). Drawn from their immediate experiences – the flat ground they walk on or the seemingly linear horizon – young children may deduce that the Earth is flat. Yet, the introduction of the idea that the Earth is spherical, perhaps via space photographs or globes, precipitates a cognitive conflict. The learners' firsthand, sensory-based belief now grapples with this newfound information.

Facilitators, such as learning about gravity's role in moulding the Earth into a sphere or hearing narratives of astronauts circumnavigating the globe, assist in resolving this conflict. With accumulating evidence supporting the Earth's roundness and reconciling it against their initial belief, learners undergo a significant conceptual change. This adaptive shift enables them to assimilate the understanding that the Earth is, contrary to their first impression, spherical and not flat.

Drawing from these examples, one can witness the tangible impact of Piaget's theories in real-world educational settings. These instances underscore the dynamic nature of cognitive development and the interplay of assimilation and accommodation in shaping a child's understanding of the world around them.

Therefore, Piaget's equilibration theory serves as a comprehensive framework for grasping how learners perceive, process and integrate new knowledge. The integration of new knowledge can be enhanced through having activities in the sensorimotor stage where physical interaction promotes basic understanding and schema formation. In the pre-operational stage storytelling (reading), art projects and elementary science experiments can be incorporated. In the concrete operational stage, hands-on science experiments and engagement in more complex problem-solving can be facilitated, and in the formal operational stage, more abstract thinking can be enhanced through advanced scientific experiments, complex mathematical problems and facilitating, for example, technology projects through artwork. The intertwined notions of cognitive conflict and conceptual change underscore the dynamic and adaptive nature of human cognition. Through diverse experiences and challenges, our understanding of the world continually refines, becoming more layered and intricate.

■ Facilitation of AhA-moments

The question now is how to facilitate teaching and learning to allow for the shift to the heuristic approach. Because of ostensive approaches and rote learning in STEAME contexts and subjects, we have the challenge of learners not grasping crucial concepts, especially the abstract concepts. A particular aspect to keep in mind is that in STEAME subjects, we have different prior concepts that need to be comprehended in order to understand a new concept that builds on it, mostly at a higher cognitive level, and therefore, it is essential that the proposed continuum is swayed towards meaningful learning and a conceptual understanding. Research has proposed different ways of facilitation to enhance such conceptual understandings. The facilitator should keep in mind that the facilitation process should assist learners to get to the 'AhA-moment'. Tulver et al. (2023, p. 2) acknowledge that insight is perceived in different ways by researchers, but propose that 'insight is not merely a specific sub-process of problem-solving, but rather the manifestation of a core process of cognition that accompanies significant changes in mental structures'. With insight, it is as if a person suddenly reaches a solution to a problem he or she has been grappling with. This sudden comprehension can result in new insight into an existing situation which can shed light on the solution to a problem (eds. Sternberg & Davidson 1995) where this sudden new insight is the result of restructuring or reorganisation of the elements of a situation or problem. Tulver et al. propose that 'insight is a central process underlying many seemingly unrelated phenomena across distinct areas of research' and insight being a common topic in problem-solving literature (2023, p. 2). More so, insight can be perceived as the display of a central process of cognition that escorts significant changes in mental structures. Insight is mostly linked to non-routine problem-solving procedures and is often differentiated from analytical problem-solving (Kounios & Beeman 2015). There arises tension from a discrepancy between the problem at hand and the solution or where the conflict is between the goal and the ability to achieve it.

Thoughtful facilitation is pertinent for ensuring that the AhA-moment is reached. The question, however, is how to effectively facilitate the teaching and learning process in reaching more of these AhA-moments – moving from the ostensive to the heuristic way of facilitation. When one understands the mechanisms that allow for insights into the context, this understanding may possibly lead to methods for facilitating innovation (Kounios & Beeman 2009).

In STEAME subjects, we need to ensure that gaps in knowledge and skills are narrowed. Students have the tendency to overestimate their abilities (Ambrose et al. 2010) which causes a challenge when they have to build on concepts not yet mastered. In order for them to identify that they do have gaps in their knowledge, facilitators (1) can use formative assessment tasks linked with feedback in terms of answers and (2) provide opportunities for self-assessment. This might assist learners to be more aware of the gaps in their own knowledge and thereafter to seek support to fill the gap.

Gaps in learners' knowledge can be addressed through scaffolding knowledge from lower-order thinking to higher-order thinking after an assessment and a diagnosis have been made. Scaffolding is the interaction between a child/ student and a parent/tutor/educator where the adult 'provides just enough support based on the progress made by the child/student on an ongoing basis' (Puntambekar & Hubscher 2005, p. 1). Scaffolding knowledge from lower-order to higher-order thinking skills resonates well with the balancing between the ostensive and the heuristic in the endeavour to reach the AhA-moments. To assist in facilitating more AhA-moments and to incorporate scaffolding, one also finds readily available computer-based learning environments such as intelligent tutoring systems, of which there are thousands for STEAME subjects. Learners frequently make use of them when they struggle to grasp concepts or when they want to revise concepts when they are on their own. These computer-based learning systems are effective in supporting conceptual development because they adapt to the individual needs of students by providing scaffolding of key learning processes systematically and dynamically (Azevedo et al. 2011). However, although computer-based learning environments are also means of SDL and are proven to be effective when applied correctly, the human aspect of facilitation provides an added advantage which Azevedo et al. (2011) call adaptive content and process scaffolding. The added human element can lead to learners regulating their learning more effectively about a challenging STEAME topic and ensuring better performance compared to SDL without any scaffolding. This is confirmed by Puntambekar and Hubscher (2005) who argue that scaffolding includes prompts and hints provided in tools to support learning. Educators can direct or encourage learners to use computer-based learning platforms to fill gaps in their knowledge, but the added human support is more advantageous.

Gone with the old and focus on the future! With that in mind, we need to also ensure that with the facilitation of effective teaching, we deliberately yield away from teacher-centred teaching and focusing on learner-centred facilitation. Research indicates that we still have situations where 'chalk-and-talk', rote learning and teacher-centred teaching are foregrounded in teaching (Sebotsa, De Beer & Kriek 2019). If educators want to move away from the ostensive continuum and lean more towards the heuristic continuum, facilitation approaches need to adopt a learner-centred approach to the facilitation of learning. Students should take increasing responsibility for their own learning where they need to diagnose their own learning needs, discover their own preferred learning style and reflect on the progress made (Lai, Gardner & Law 2013). Self-directed learning is described by Sebotsa et al. (2019) as:

> [*A*] process by which individuals take the initiative, with or without the assistance of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. (p. 338)

In the process, they learn to become autonomous learners. This process requires a specific kind of facilitation and mindset of the educators. They need to know and apply fitting ways of energising and examining the SDL of their learners.

Another pertinent aspect to consider as a facilitator is to assist students in assessing what knowledge is required in a task in order to successfully complete it (Ambrose et al. 2010). This can be done through being more explicit in your instruction on your objective, expressing that which you do not want, checking learners' understanding of tasks and providing performance criteria such as an assessment rubric to assist learners on the requirements of the task. In that way, incorrect paths are reduced when they work on tasks. Therefore, Lindeman (1926, p. 139) proposes that the following questions can be posed when a problem-solving task is facilitated: (1) What situation have we here? (2) What sort of problem does it show? (3) What new information does it involve? [and] (4) What action will set us on towards a solution? These questions might facilitate learners' thinking towards purposeful and fitting solutions to problems.

'Openness' to learning is also among the traits of SDL (Cazan & Schiopca 2014). To enhance openness, the facilitator should display that property to himself or herself and create a conducive environment for openness to be encouraged. Motivation, self-monitoring, self-control and self-confidence are also other important qualities (Askin Tekkol & Demirel 2018) to have that enhance SDL and problem-solving. These are more qualities to consider when facilitating learning.

Lai and Gardner (2013) investigated an intervention designed to assist practising teachers in facilitating SDL, and they argue that in the literature, little attention had been paid to help assist existing educators with limited experience of SDL, or even those in training, to prepare or become facilitators of SDL. Through this specific investigated intervention, the participants' attitudes towards SDL increased even more, and they valued practical advice. However, they did not see the connection between in-class activities and learners' SDL. This alludes to the difficulty in bringing about change in facilitation skills among teachers, leaving the education landscape unchanged in this regard. There is also a scarcity of research which reports on educational systems aiming at fostering learners' SDL competence although the importance thereof is 'recognised and classified as a priority educational goal' (Morris 2019, p. 645).

Conclusion

The transmission mode of teaching needs to make way for other modes of teaching where learners are less reliant on their educators. It is important for learners and educators to see that learners (and educators) should develop flexible behaviour if they want to adapt to fluid and complex social contextual changes (Morris 2019). They need to be able to navigate solving real-world problems situated in their work or personal contexts which require a flexible approach to problems that do not occur repeatedly but change because of a changed context. Therefore, SDL should be fostered in formal educational settings (Morris 2019). This can be done by including in the facilitation (1) setting the initial mood or climate of the experience; (2) enabling a collaborative setting of learning objectives with learners; (3) providing access to the widest possible range of resources for learning; (4) welcoming all opinions and attitudes towards the content in an unbiased way; (5) working towards a share of control of directing the means and objectives of learning between educator and learner(s); and (6) not imposing how learners choose to construct meaning (p. 638).

The question therefore is: How should interventions be structured to guide teacher professional development on how to enhance SDL? So, first of all, a learning environment should be created where educators are guided to be more self-directed where they themselves identify their own learning goals as well as manage their own learning effectively (Sebotso et al. 2019). Professional development (PD) interventions should consider including situations where cognitive dissonance is experienced so as to propel educators to set personal learning goals for themselves. However, personal learning goals should be balanced with societal needs (Morris 2019). Workplace simulations, e-portfolios and development portfolios can be used to facilitate SDL. Educators should also consider the learners' social context to enhance their SDL. Hence, careful choice of tasks should be ensured. Educators should be trained in how to facilitate SDL in the formal setting as SDL in the formal setting might be the prerequisite to enable competent SDL in informal learning settings (Morris 2019). Professional development interventions should also ensure that educators give learners support when they are busy with SDL tasks. Too easily learners can get despondent when they get side-tracked and their confidence can diminish, but this can be addressed through personal feedback from the facilitator or even a peer. If facilitators consider all the mentioned aspects, a more balanced means of learning through facilitation and promoting the heuristic in STEAME teacher education will be ensured.

Chapter 5

Foundation Phase teaching and learning and the affordances of coding and robotics

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Abstract

The integration of computational thinking, coding and robotics in early childhood education has gained significant attention in recent years. Coding and robotics are great methods for introducing computational thinking. However, the integration of these fundamental skills into formal

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and official curricula within a South African context has been drafted and is about to be implemented. This is still a challenge with pre- and in-service educators needing pedagogical perspectives to properly integrate computational thinking concepts, robotics and coding into their classrooms.

This chapter will focus on the discussion of the Foundation Phase curriculum, from a computational thinking perspective by focusing on the introduction of coding and robotics. Teachers should have the confidence and capability to incorporate computational thinking, coding and robotics into both official and informal curricula. Foundation Phase teachers will be introduced to play pedagogy as learners in this phase learn best through play. Play is part of a child's daily life and therefore the best approach to engage children in learning. A play-based teaching approach makes use of young learners' natural enthusiasm and inquisitive nature to explore and learn new concepts. Effective strategies, especially play-based teaching, could therefore be utilised to introduce 'robotics, coding and computational thinking' into the foundation phase. Foundation Phase learners can also be gradually guided towards self-directed learning, although they are at the beginning of their journey in education. The challenges faced by introducing such a curriculum will be highlighted as well as the way forward. This chapter will make recommendations for informing practices in the training of student teachers, teachers and other role players, specifically in terms of the Coding and Robotics curriculum. Future developments will also be mentioned.

■ Introduction

The introduction of computational thinking (CT), coding and robotics in early childhood education is upon us. Coding and robotics are excellent tools to achieve the goal of introducing CT. However, the integration of these fundamental skills into formal and official curricula within a South African context has been drafted and is about to be implemented. It was announced that coding and robotics will be introduced in the Foundation Phase curriculum in South African schools in 2024 (Department of Basic Education [DBE] 2022).

This is still a challenge as pre- and in-service educators require pedagogical perspectives to appropriately integrate CT concepts, robotics and coding into their lessons.

This chapter will focus on the discussion of the Foundation Phase curriculum from a CT perspective by concentrating on the introduction of coding and robotics. Teachers should have the capability and confidence to incorporate CT, coding and robotics into the activities of both official and informal curricula.

Based on global trends and the instructional time in the Foundation Phase being Grade R (1 h), Grades 1–2 (1 h) and Grade 3 (2 h), the introduction of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) programmes has focused on the hands-on elements of working with robotics, which help strengthen fine motor skills, while also emphasising the importance of introducing coding to young children early, before the emergence of stereotypes (Bers, Seddighin & Sullivan 2013). Children can learn through play and developmentally appropriate robotics activities that include 'problem-solving, abstract reasoning, and logical thinking' (Bers 2018, p. 6).

What coding and robotics is and how it is related to Foundation Phase curriculum and child development

According to the Basic Department of Education, the Council of Education Ministers approved the implementation of a Coding and Robotics curriculum in the Foundation Phase in 2018. The Department, in conjunction with the University of South Africa (Unisa), has developed a Coding and Robotics curriculum for the GET Band, from Grades R to 9. According to Basic Education Minister, Motshekga (2018), 'the coding curriculum will develop learners' ability to solve problems, think critically, and work collaboratively and creatively; function in a digital and information-driven world; apply digital and information and communication technology (ICT) skills; and transfer these skills to solve everyday problems' (Miller, 2019, p. 1)

It is proposed that the Coding and Robotics curriculum be introduced as a subject and not be integrated into various other subjects, and this might also create the impression that only certain learners would be inclined to do coding at later stages in their careers; the curriculum's ultimate goal is to steer learners into the engineering field. It is our intention to motivate the integration of coding and robotics into all spheres of school subjects. Many educationists would argue for the subtle introduction of coding and robotics by applying CT in early childhood education, and the CT proposition focuses mainly on applying coding theoretical concepts without using devices such as computers, tablets and robots. In many well-developed education systems, curricular devices were introduced at the early stages of foundation teaching. There is an argument that children in early childhood stages (Grades R–1) should not be encouraged to use devices, but this can be challenged as children have the ability to use these devices from a very young age. This is what gave rise to the development and implementation of the Foundation Phase curriculum.

The Foundation Phase curriculum

As mentioned above, in 2018, the Council of Education Ministers, as reported by the Basic Department of Education, approved the introduction of a Coding and Robotics curriculum for the Foundation Phase. This subject is crucial for thriving in a digital, information-centric world by teaching digital ICT skills and applying them to solve everyday problems, thereby fostering the development of learners. It encompasses various interrelated fields within information technology and engineering, focusing on activities that address problems through logic and CT (DBE 2019).

The *Curriculum and Assessment Policy Statement (CAPS)* (DBE 2019) outlined that the subject Coding and Robotics in the Foundation Phase (Grades R–3) is divided into five study areas: Pattern Recognition, Algorithms and Coding, Robotic Skills, Internet and e-Communication, and Application Skills. This structure is designed to ensure that the foundational skills, values and concepts essential for early development and for subjects taught in Grades 4 to 9 are established and nurtured in Grades R to 3. The Foundation Phase curriculum integrates Beginning Knowledge and Personal and Social Relationships into these topics. Coding and Robotics is a multidisciplinary subject that enhances and supports other core Foundation Phase subjects, such as Languages (Home Language and First Additional Language) and Mathematics (DBE 2019).

Specific aims

The subject Coding and Robotics aims to equip learners with the skills to solve problems, think critically, collaborate and adapt in a digital world. It emphasises teaching digital skills for everyday problem-solving while fostering creativity and collaboration. The curriculum is designed to prepare learners to thrive in a rapidly changing society. It encompasses aesthetic, cognitive and creative skills through activities such as dance and art; imparts digital and ICT skills through technology and CT; fosters an understanding of social relationships and the environment; and contributes to physical, social and emotional development (DBE 2019).

Time allocation for teaching Coding and Robotics in the proposed curriculum

Table 5.1 shows the total time allocated to Coding and Robotics per week for the three grades in the Foundation Phase programme.

TABLE 5.1: The instructional time in the Foundation Phase.

Subject	Grade R (h)	Grades 1–2 (h)	Grade 3 (h)
Home Language	10	8/7	8/7
First Additional Language		2/3	3/4
Mathematics	7	7	7
Coding and Robotics	1	1	2
Life Skills:	6	6	7
• Beginning Knowledge	(1)	(1)	(2)
• Creative Arts	(2)	2	(2)
• Physical Education	(2)	2	(2)
• Personal and Social Well-being	(1)	(1)	(1)
Total	**(24)**	**(24)**	**(27)**

Source: DBE (2019).
Key: h, hours.

Focus content areas

The Coding and Robotics subject in the Foundation Phase emphasises several key content areas: Pattern Recognition and Problem-Solving, Algorithms and Coding, Robotic Skills, Internet and e-Communication Skills, and Application Skills. These strands are interconnected, focusing on application, knowledge and skill development. The subject is based on CT and the Engineering Design Process.

The curriculum is designed to be hands-on and practical, with activities that are formally assessed and integrated into teaching time. Additionally, informal assessments are conducted throughout lessons, even when students are not participating in performance assessment tasks (PATs). This practical approach aims to cultivate a thorough understanding of coding, robotics and associated skills among students during their Foundation Phase (DBE 2019).

Coding and Robotics resources

The subject emphasises the importance of well-rounded educational resources for teaching Coding and Robotics. The department emphasised key points including the ones listed below.

1. *Learner resources*: Students should have access to textbooks, workbooks or e-books, with schools implementing book retrieval policies if needed.
2. *Teaching tools and materials*: Schools must provide necessary tools, devices, materials, and consumables for effective teaching, learning and assessment. Regular organisation and checks are essential.
3. *Subject-related magazines*: Schools are advised to subscribe to at least two subject-related magazines to keep teachers updated on industry developments. These should be accessible to both teachers and students.

4. *Coding and Robotics lab*: Institutions offering Coding and Robotics courses need a well-equipped lab with secure and spacious storage for resources to facilitate Practical Assessment Tasks.
5. *Teacher resources*: Teachers should have access to reference books, e-books, charts, brochures and the internet to stay current with industry trends. Digital tools should be utilised for information sharing.
6. *Teacher training*: Teachers require training not only in the subject's content but also in its context and effective teaching methods.
7. *Responsibility for resources*: Schools are responsible for obtaining Coding and Robotics teaching resources and encouraging donations from students, parents, workshops and suppliers.
8. *Resource inventory and audits*: All resources should be listed in an inventory and audited regularly. Availability for both internal and external audits is crucial.
9. *Sustainable support*: Coding and Robotics education demands consistent support. The lab needs ongoing resourcing for practical tasks and maintenance to ensure sustainability.

Overall, the policy emphasises the importance of a well-equipped learning environment with up-to-date resources to facilitate effective teaching and learning, especially in subjects involving technology and innovation (DBE 2019).

Coding requirements

The curriculum discusses the considerations and requirements for setting up a Coding and Robotics lab in a school. It emphasises the need for the school management team (SMT) to carefully plan the budget for the lab (DBE 2019). The budget should cover not only practical tasks for students but also tools, consumables, experiments, demonstrations and simulations for teachers. The budget should include software licenses, supplies such as paper and cartridges, maintenance, insurance, internet connectivity and a sustainability plan.

Teachers should have the flexibility to enhance teaching with additional materials such as posters, models, videos and periodicals. Regular maintenance and provisions for equipment failures should be accounted for. Obsolete tools, consumables and equipment should be phased out and replaced as necessary.

For coding requirements, the lab should have free open-source software for block-based coding and code cards with basic coding instructions. In terms of robotics requirements, the lab should have basic electrical components such as switches, batteries, wires, Light Emitting

Diodes (LEDs), motors and more. It should also have basic mechanical components such as wheels, pulleys, gears and fasteners. These components might be made from recyclable materials (DBE 2019).

If there is a commitment from the Education Department to effect the necessary formulation and implementation of the curriculum, it should be made very specific and practical to all the people involved in the curriculum. The declared commitment referred to must translate into concrete things on the ground; in other words, the curriculum implementation should be clearly visible and noticeable to one and all.

With a clear Foundation Phase Coding and Robotics curriculum in place as discussed above, it is imperative that the learners be prepared for such a curriculum. The curriculum highlights the importance of developing skills such as critical thinking and problem-solving. A highly effective way to cultivate these abilities in learners is through the introduction of CT, which is especially valuable for teaching 21st-century skills where critical thinking and problem-solving are essential components.

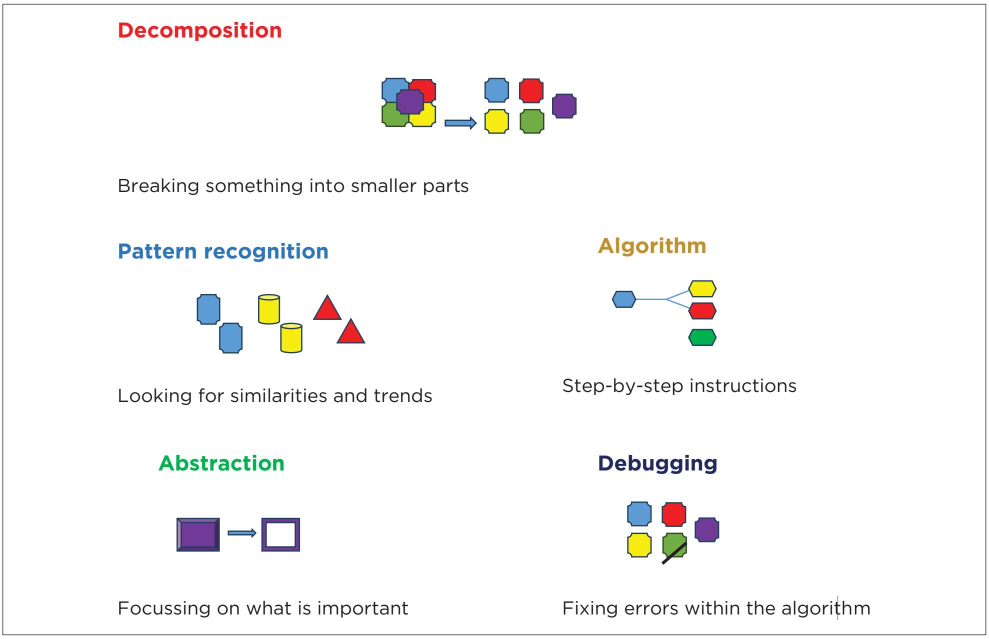
What is computational thinking?

Computational thinking involves problem-solving, system design and understanding human behaviour by applying core principles of computer science. It involves a variety of mental tools that represent the wide scope of the computer science field (Wing 2006).

Computational thinking is essentially a framework that outlines critical thinking and problem-solving abilities. It has become widely recognised as an effective method for teaching these skills in formal educational environments. Computational thinking is a process where we use coding or programming to communicate with computers to let them do tasks, create websites, process data and solve problems. In Figure 5.1, CT can be categorised into five key techniques: Algorithm, Abstraction, Debugging, Decomposition and Pattern Recognition.

Pattern recognition identifies similarities within and among problems, including adaptable or reusable solutions to similar issues. Algorithms are like a recipe creating a precise, step-by-step set of instructions or rules to achieve a specific outcome, which can be followed by a human or a computer. Abstraction means concentrating only on the crucial information and disregarding irrelevant details. Decomposition means breaking down a complex problem or system into smaller, easier-to-handle components.

Although CT is not the sole approach for developing these skills, it offers a perspective on problems that helps in designing automated



Source: Based on the DBE (2019, p. 9).

FIGURE 5.1: Five key techniques of computational thinking.

solutions or semi-automated solutions by leveraging the distinct benefits of computers. It also offers benefits by establishing a common language, providing abundant resources and fostering an active community of practice that supports educators in refining, coordinating and enhancing their efforts to teach problem-solving skills to future generations (Hunsaker 2020). Learning CT offers both economic and academic advantages for learners. Each year, the number of new computing jobs significantly exceeds the number of computer science graduates, with substantial job growth expected to continue in the coming years (Bureau of Labor Statistics 2018).

Furthermore, studies have linked learning CT to various academic advantages, such as improved student engagement, motivation, confidence, problem-solving skills, communication abilities and better performance in STEAME subjects (Rich et al. 2017; Yadav, Stephenson & Hong 2017). In our rapidly advancing and high-tech world, it is clear that learners need to develop critical thinking skills and the ability to solve complex, unclear problems to succeed in the digital world where they will 'live and work' (Schön 1987; Ventura, Lai & DiCerbo 2017). The consensus on the significance of teaching critical thinking and problem-solving skills in schools is mixed, with disagreements on methods, timing and terminology.

One way to teach these skills is through CT. Computational thinking is particularly significant in the 21st century, the computer age, as it not only promotes critical thinking but also highlights the importance of assisting students in 'developing and employing strategies to comprehend and address problems by harnessing the power of technological methods to create and test solutions' (ISTE n.d.). While CT is crucial for computer scientists, it is also very well suited to solving many problems, both academic and non-academic.

Why computational thinking?

Most studies on CT, robotics and coding have concentrated on the later stages of schooling. Introducing these concepts and skills during the Foundation Phase can have a beneficial impact on promoting STEAME when integrated naturally and playfully with social science.

Computational thinking serves as a framework that describes a collection of crucial critical thinking and problem-solving skills. It has earned substantial recognition as a practical and effective approach for teaching these skills within formal educational environments (Hunsaker 2020).

Although CT:

> [*I*]s not the only way to a addressing these skills, it offers a perspective at problems so as to produce an automated or semi-automated solution that takes advantage of the unique affordances of computer technologies. (Hunsaker 2020, p. 96)

It also proves advantageous by offering:

> [*A*] common vocabulary, a wealth of resources, and a vibrant community of practice for teachers seeking to focus, coordinate and improve efforts to guide rising generations in developing problem solving skills. (Hunsaker 2020, p. 96)

According to Hunsaker (2020), learning CT can have dual advantages for learners, impacting both their economic prospects and academic achievements. Furthermore, studies have associated numerous academic advantages with CT learning, such as increased student engagement, motivation, confidence, problem-solving skills, communication abilities and enhanced performance in STEAME subjects (Rich et al. 2017; Yadav et al. 2017).

Integration of computational thinking into Foundation Phase education

Our DBE underscores the importance of integrating CT in the Foundation Phase and Intermediate Phase education.

Establishing a way of CT takes time, so to ensure that future professionals truly grasp CT, it is essential to introduce 'these concepts early' and consistently 'throughout their academic career' (Yadav et al. 2014). Given its 'cross-disciplinary' nature (Yadav et al. 2017), teaching CT in elementary or even preschool settings is logical, where subjects are naturally integrated for learners within the same environment. Research indicates that children as young as preschool age (around four years old) can 'successfully learn basic CT concepts' (Bers et al. 2014; Sullivan & Bers 2016). Additionally, studies show that this learning process can be 'an engaging and rewarding' experience for the learners (Bers et al. 2014).

Technology is deeply integrated into our daily lives. According to Bers et al. (2013), given the significant role technology plays in children's lives, it should be included in early childhood education, with CT being an effective approach. While early education often focuses on understanding the natural world, the man-made world is equally crucial. Many children are more familiar with cell phones than polar bears, yet educators tend to teach more about polar bears than cell phones. Both should be included in educational curricula (Bers et al. 2013):

> Some early childhood practitioners may question the appropriateness of teaching computational thinking to very young students, due to prevalent and well-founded concerns about giving too much screen time to young children. (NAEYC & Fred Rogers 2012, p. 100)

Nevertheless, these concerns can be reduced by understanding that:

1. there are numerous CT activities that do not involve the use of a screen (e.g. unplugged activities and screen less robots), and
2. even activities that do involve screen time can – and should – be constructed as interactive, rather than non-interactive uses of technology (NAEYC & Fred Rogers 2012, p. 2).

Coding and Robotics in early childhood

Most research on robotics, coding and CT has concentrated on later stages of education. However, introducing these concepts and skills during early childhood can positively promote STEAME when integrated with social sciences in a natural and playful manner. Modern robotic kits designed for young children facilitate learning through manipulatives. Resnick et al. (1998) and Bers, González-González and Armas–Torres (2019) demonstrate how these tools enhance the understanding of mathematical concepts, similar to traditional materials such as blocks, beads and balls. Additionally, robotics activities typically do not involve screen time and can encourage teamwork and collaboration (Sullivan & Bers 2016).

Previous research has demonstrated that young children aged four to seven can create and programme basic robotics projects (Cejka, Rogers, & Portsmore 2006; Sullivan & Bers 2013; Wyeth 2008). Additionally, working with robotics helps develop other essential skills such as fine motor skills and hand-eye coordination (Bers et al. 2013; Hill et al. 2016; Lee, Sullivan & Authors 2013). Moreover, coding and robotics enable children to develop problem-solving, metacognitive and reasoning skills (Elkin et al. 2014).

However, when introducing robotics into early childhood education, it is crucial to adopt a pedagogical approach that is developmentally appropriate. Using various metaphors can help achieve this. For example, Resnick (2006) compared programming to a paintbrush, viewing it as a tool for self-expression and creative design. Similarly, Bers (2018) described robotics as 'coding as a playground', highlighting its ability to engage children cognitively, socially, physically, emotionally and creatively.

■ Why integrate computational thinking in early childhood and primary school education?

Developing a specific way of thinking takes time; therefore, 'to ensure that future professionals fully grasp CT, it's essential to introduce these concepts early and reinforce them consistently throughout their academic careers' (Yadav et al. 2014, p. 14).

Computational thinking is inherently 'cross-disciplinary' (Yadav et al. 2017), making it logical to begin teaching it in elementary school or even preschool, where subjects are naturally integrated within a single learning environment. Research indicates that children as young as preschool age (around four years old) can successfully grasp basic CT concepts (Bers et al. 2014; Sullivan & Bers 2016).

Research also indicates that learning CT can be 'an engaging and rewarding' experience for students (Bers et al. 2014). Introducing new ways of thinking through computer science is vital, as computer programming is becoming an essential skill in the 21st century.

■ Unplugged coding

Futschek and Moschitz (2010) argue that algorithmic thinking, a crucial aspect of coding for children, should be simplified to a level that they can comprehend. Teaching coding through activities, rather than using computers, which can be too complex for young children, aligns better with their developmental stage and the educational process at an early age (Futschek & Moschitz 2010).

This approach is considered an 'unplugged' method for teaching coding and robotics, focusing on understanding CT and its practical applications without reliance on computers or devices. Conversely, alongside computer use, children of various ages can benefit from a diverse and engaging learning experience by experimenting with robotics, which integrates programming and design (Cejka et al. 2006).

Metin (2020) emphasises the significance of coding education programmes tailored for preschoolers, stressing the integration of children's developmental characteristics with the curriculum. Learning in children occurs through active participation (Piaget 1970) and their interactions with adults and peers, aligning with cognitive development and learning experiences.

Early childhood is a crucial time when children explore their surroundings through play. To foster basic coding skills during preschool years, children should engage in pre-coding activities that build foundational knowledge, such as understanding directions.

Metin (2020) suggests that many concrete data processing environments are overly complex for children to grasp and comprehend. Therefore, it is crucial for children to initially learn coding without computers, using unplugged methods. Computers are intricate and their applications involve numerous integrated functions that can be daunting for users. Thus, incorporating play is essential to introduce these young learners to these intricate processes.

Play pedagogy

Foundation Phase learners are between five and nine years of age. Teaching in the Foundation Phase is therefore focused on children's development, guiding them to acquire specific skills such as cognitive, language, social, affective and physical skills. Play is seen as an important factor in the cognitive and social development of young children (Trawick-Smith, Swaminathan & Liu 2015, p. 1); they learn through play. The Italian physician and educator, Maria Montessori said that '(p)lay is the work of the child' (Liu, Choy, & Tsang 2017, p. 1). Samuelsson and Carlson (2008) demonstrated that children make sense of their world through play and create knowledge through play. Therefore, any developmentally appropriate childcare programme or curriculum for those learners should focus on play. Englebright (n.d.) states that play is where children learn about the world, themselves and others, thereby beginning to socialise. When children play, they draw on their previous experiences and use these experiences to construct games, play scenarios and participate in tasks. According to Hadebe (2015, p. 11), play is a 'free and voluntary activity, a source of joy and amusement', which is joined in for the recreational purpose, not aimed at a specific goal or practical purpose. Children are usually fully engrossed in their play and they are intrinsically motivated to play. Play also facilitates the holistic development of physical, emotional, socio-cultural and cognitive abilities (Hadebe 2015, p. 14).

What is pedagogy of play?

Table 5.2 provides an overview of the characteristics of Pedagogy of Play.

Davin (ed. 2013) highlights that play is often overlooked and undervalued, yet its importance in the Foundation Phase cannot be overstated (eds. Excell & Linington 2015). It encourages and creates learning experiences because it is usually meaningful, joyful, iterative and socially interactive and involves active engagement (United Nations Children's Fund [UNICEF] 2018). According to the Lego Foundation, play is joyful because it brings laughter and delight and feelings of competence, especially when they master an activity or task with a bit of support (Lego Foundation Online Course). Play is characterised by initiation, decision-making, self-choice and control of the play experience (UNICEF 2018).

According to Samuelsson and Carlsson (2008), play and learning are natural components of a child's daily life. Research has shown that young children are naturally curious about their environments and want to explore what is in their environment. Play also encourages and creates learning experiences because it is usually meaningful, joyful, iterative and socially interactive and involves active engagement (UNICEF 2018). Play is part of a child's daily life, and therefore, the best approach is to engage children in learning. The association between play and cognitive development has

TABLE 5.2: What is pedagogy of play?

1.	Play and learning are integral elements of a child's daily life, with play serving as a catalyst for various learning experiences.
2.	According to Vygotsky, play plays a crucial role in fostering cognitive, social and emotional development in children.
3.	Additionally, play contributes to the establishment of self-directed learning in a child's educational journey.
4.	A play-based teaching approach leverages the innate enthusiasm and curiosity of young learners to explore and grasp new concepts.
5.	Through play, children practice skills, experiment with possibilities and engage in exploration and discovery, leading to a deeper understanding of new knowledge.
6.	Furthermore, play-based learning serves to reinforce previously taught concepts, as children demonstrate their comprehension verbally or non-verbally during play activities (Evans 2021, pp. 34–35).

Source: Authors' own work.

been presented in more detail in Piaget's and Vygotsky's cognitive development theories. Vygotsky believed that play promotes children's cognitive, social and emotional development.

Good and Ottley (2019) argue that choice can be a motivating tool that encourages learners to participate and complete challenging activities and enables children to become responsible for their own learning. This indicates that play could also assist in establishing self-directed learning at this very early stage in the Foundation Phase of learners and their journey through education. Play helps them to make sense of the world around them, learn about themselves and find meaning in real-world experiences. They play to practise skills, experiment with new possibilities, and explore and discover new challenges which could lead to a better understanding of new knowledge. Play is part of a child's daily life, and therefore, the best approach is to engage children in learning. Educators should employ the use of different kinds of play in the process of transferring knowledge to young learners. A play-based teaching approach makes use of young learners' natural enthusiasm and inquisitive nature to explore and learn new concepts**.** Furthermore, play-based learning helps to solidify the concepts already taught as children demonstrate their understanding through play, whether it is verbally or non-verbally (Evans 2021, pp. 34–35).

Thus, robotics, coding and CT could be brought into primary school classrooms using effective teaching techniques, especially game-based learning. However, the pedagogical strategy for introducing robots in early childhood must be developmentally appropriate. Different metaphors can be used to explain this. Thus, Resnick (2006, pp. 192–208) compares programming to a brush, describing it as a tool for creative design and self-expression. Because robots can engage children cognitively, socially, physically, emotionally and creatively, Bers (2018) likens it to 'coding as a playground'.

Benefits of pedagogy of play

Table 5.3 provides an overview of the benefits of the Pedagogy of Play.

TABLE 5.3: Benefits of pedagogy of play.

• Play is considered the essential work of a child, serving as a means through which they comprehend and navigate their world.
• In the process of play, children generate knowledge by drawing upon their past experiences to construct games, scenarios and tasks.
• Play is a voluntary and joyful activity that is intrinsically motivating for children, capturing their full engagement.
• Importantly, play contributes to the holistic development of physical, emotional, socio-cultural and cognitive abilities in children.

Source: Authors' own work.

The main aims of the Coding and Robotics subject

The goal of the robotics and coding courses is to help students become problem solvers, critical thinkers, creative collaborators, users of digital and information-based technologies, users of digital and ICT skills, and users of those abilities to address real-world issues. It also creates opportunities such as preparing students for fulfilling lives in a culture that is changing quickly.

Affordances for Foundation Phase teachers: A critical review

In order to properly teach the Foundation Phase learner, a Foundation Phase teacher should be a specialist in his or her field, as the acquisition of knowledge is not the only aspect to focus on. The Foundation Phase teacher's focus is the optimal and holistic development of the child. In the acquisition of aspects such as language development and effective social, physical, creative and moral development of the learner must also be emphasised (ed. Davin 2013). Foundation Phase learners should acquire skills that learners in other phases have already obtained. The teacher should have the skills to make learners grasp the fundamentals of mathematics, language, reading and in this era also the introduction to robotics, coding and CT, eventually leading learners at this very young age, to self-directed learning through play-based teaching.

Young children are eager to discover and fuel their higher-order thinking skills through play-based activities (Nieman & Monyai 2006). Coding and Robotics 'can engage children in a playful and developmentally appropriate learning experience that includes problem-solving, abstract and logical thinking' (Bers 2018) even at this very young age, if guided properly by the teacher.

Teachers and pre-service teachers/student teachers should therefore also be trained to effectively and efficiently teach the Coding and Robotics subject. In effect, it means in-service training should occur to appropriately equip and empower Foundation Phase teachers, and the teaching of coding, robotics and CT should be included in the training courses offered to student teachers. Such training courses should consist of in-depth content knowledge of the Coding and Robotics subject as well as appropriate teaching techniques and strategies.

The classroom environment

According to Nieman and Monyai (2006), learners achieve optimal learning in an environment that encourages play, exploration and discovery. They also require socialisation and stimulation in a welcoming setting (Englebright n.d., p. 1). Children emulate adults when they are given the freedom to utilise their imaginations and build their own worlds. Vygotsky argues that learners have a tendency to create opportunities for themselves to develop intellectually by imitating adults during their play. Therefore, creating a positive environment in the classroom with appropriate resources and enough space for learners to engage, interact and explore will help them build confidence, acquire competence and develop an eagerness to enter the 'coding playground'. Research has indicated that children in the Foundation Phase can programme using robotics (Bers et al. 2002; Cejka et al. 2006; Scharf et al. 2008; Sullivan & Bers 2013; Wyeth 2008). Futschek and Moschitz (2010), however, state that algorithmic thinking, an imperative process of coding for children, should be brought down to a level where it is easy for young children to understand. Computers can be very intricate and confusing for children in the Foundation Phase, even in the 21st century; therefore, learning coding through activities would be more suitable for the nature of the children's development and educational processes (Futschek & Moschitz 2010).

A positive classroom climate and effective teaching strategies, especially play-based teaching, could therefore be utilised to introduce robotics, coding and CT into the Foundation Phase.

Challenges

With the introduction of every new programme or subject, there are always challenges before the subject can be incorporated properly. In the case of the subject Coding and Robotics, the following could be possible challenges:

- Finances are the costs involved to procure the necessary infrastructure such as a Coding and Robotics lab that is properly equipped for learners to work in and complete the Practical Assessment Tasks. There should be enough storage space for resources in the Coding and Robotics lab; a wide variety of reference books, e-books, charts and brochures in the classroom; and e-mail, access to the internet and cloud storage facilities. Independent schools might be able to fund themselves to procure the necessary infrastructure, but public schools that are dependent on the Department of Education could once again be marginalised.
- In-service educators and student teachers need appropriate pedagogical perceptions and skills to effectively and efficiently integrate CT concepts, robotics and coding into their classrooms in order for their learners to

benefit optimally from it. Identification of specific skills the educators need and robust training would be necessary in order to equip educators and pre-service educators for the effective teaching of the Coding and Robotics subject.
- All schools with well-equipped Coding and Robotics labs and all infrastructure should be secured, if necessary, security guards have to be appointed to further ensure the safety of the infrastructure.

Conclusion

Incorporating coding and robotics into the education curriculum poses a significant hurdle, as evidenced by past challenges encountered when introducing new educational policies. The successful implementation of such initiatives hinges on the willingness of key implementers to adopt feasible changes, given adequate support. Research indicates that the execution of policies is influenced by factors such as the comprehension, beliefs, attitudes, knowledge, resource availability and experiences of those responsible for implementation. If the Education Department is dedicated to ensuring both the development and execution of the curriculum, the commitment should be clearly outlined and practical for all individuals involved in the curriculum.

Chapter 6

Language, literacy and STEAME education

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Abstract

The language of science, with its disciplinary jargon and genre conventions, poses a challenge to most learners. The task for science education is thus to mediate epistemological access to this scientific discourse. This involves bridging or scaffolding learners from the oral-like language of everyday

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speech along a mode continuum to science literacy. In the process, learners' funds of knowledge and indigenous knowledges become points of departure for scientific exploration.

What compounds this challenge is when home languages are not used for schooling. Because of the hegemony of English in South African education, the majority, who speak African languages first, experience disadvantage and alienation in the science classroom. This is the case *mutatis mutandis* in most post-colonial African societies. Recent policy developments in language education give rise to the hope that official multilingualism may finally move beyond the merely symbolic and make a material difference in learners' lives.

This chapter focuses on language as a medium of instruction in the science classroom, the role of language in conceptual understanding and how language barriers could be overcome within a multilingualism-as-resource orientation. Consequently, pedagogies such as translanguaging and the genre-based approach are explored to facilitate epistemological access. We focus, firstly, on the sociology of language (in South Africa), using a critical realist lens to highlight the entanglement of language and literacy with race, ethnicity and class. Secondly, we look at genre pedagogies and multimodality as ways of scaffolding epistemological access. Finally, we foreground (pedagogical) translanguaging as a critical resource for learning in the multilingual science classroom.

Introduction

Sociology of language

Schools and society are integrally linked, and classrooms may be considered a small-scale version of society as the socio-political and cultural context is certainly reflected in classrooms. The interplay of the outside and inside world of the classroom is complex.

We note, particularly in the South African township and rural schools, the stark alignment of schools and society and where the classroom reflects the under-serviced, disadvantaged and poverty-stricken social situation. In contrast to the schools for the majority of black and poor children, well-resourced suburban schools – reserved for classified white learners prior to the end of racial segregation – cater to the high-tech new capitalist world. It is imperative for scholarship on language and scholastic achievement to consider and problematise the material conditions of children who are marginalised in society, and as is evident in this chapter, because of racial and class factors. Inequality in political, economic and social systems based on race and class is central to poor achievement and low literacy levels among marginalised learners.

South Africa is a world apart characterised by two parallel economies and societies, a limited middle-class suburban space and the 'other' excluded space where the vast majority of black working-class people live – spaces labelled townships, informal settlements, ghettos and slums. The health, economic, housing, unemployment and psycho-social difficulties in the 'othered' space are glimpsed by the high levels of protest and resistance, a condition that has led to South Africa being considered the protest capital of the world. Interestingly, the protests and resistance occur mainly in the subaltern and 'othered' spaces further reinforcing the notion of two different worlds. According to Alexander et al. (2018), on average, more than 11 protests occurred every day across the country in 2017.

The bifurcation of South African society into black and white spaces is reflected not only in the schools but also, more importantly, in the achievement levels of learners and the language codes used in the classroom. Language is an essential and fundamental aspect of society, and it is evident in the fact that African languages are used in the Foundation Phase in schools only for black children while English and Afrikaans are used in advantaged schools in the middle-class suburbs. Criticism of this reductionism may be valid; however, the reality is that schools are now class based; in other words, there is a continuity with regard to the previous racial dichotomy, as only middle-class black parents can afford to pay the exorbitant fees charged at previously white schools. The latter creates a situation where only previously white schools are 'diverse' (enrol middle-class learners from different races who can afford the school fees) while the township schools for black children remain homogenous (only black and not different from the racial policy for public schooling of the Apartheid regime). We also witness this continuity of the Apartheid dispensation in the levels of achievement of learners in the advantaged and disadvantaged schools. Achievement, for example, in literacy and numeracy audits in the Foundation Phase, is extremely low in black schools. Not only are they largely non-fee-paying schools; almost all learners rely on the school feeding scheme for their daily meals. These schools typically have insufficient physical classroom spaces, a lack of libraries and too few qualified teachers. Learners suffer inappropriate pedagogies, safety and security challenges, and the horrors of pit latrines that have caused deaths almost annually.

In this chapter, language is viewed as a site of cultural struggle and a system of communication that either confirms or denies the life histories of people who use them (ed. Macedo 2007, p. 2). Post-Apartheid South Africa has witnessed how English has become the dominant language across the school system, and apart from the use of African languages as media of instruction in the Foundation Phase, the education system, parents and society at large support the hegemony of English over other languages.

Even Afrikaans medium schools have had to change their language policies to include English in order to accommodate black learners, the majority of whom do not speak Afrikaans. Even at higher education (HE) level, Afrikaans universities were instructed by the state to include English as a medium of instruction as Afrikaans excludes black students. English is not only the dominant language of schools and universities but also central to the media, national and provincial levels of government, entertainment and social events. All South African universities claim to include three or two official languages in their institutional language policies, but in reality, English is the main medium of instruction and seems indispensable to every academic activity: graduation ceremonies, public lectures, research activities and governance matters.

Learners from well-resourced and advantaged schools generally enter university with good language and academic literacy skills. Learners from disadvantaged schools and communities struggle with articulation, enunciation and basic communication skills in English, and this has a major influence on their scholastic achievement. Basically, language plays a similar role in achievement in school and HE. Liyanage and Canagarajah (2019) write about the 'shame' children experience because of their poor English. Good English skills, an important form of social capital, confer a higher status and also lead to social stratification in schools and universities. Chimbutane (2023) argues that although schools claim to be multilingual and respect the principles of diversity, their practices and ethos are often assimilationist and colourblind. The latter is evident in South Africa where previously advantaged schools that have opened their doors to black children continue to advocate a 'monolingual' or limited bilingual language and education policy in terms of which English is dominant, and African languages are either on the periphery or absent.

To contextualise the debate, it is crucial to note how the Apartheid language policy continues to influence the current language debates and discourse. Compulsory mother-tongue instruction was the cornerstone of the Apartheid language dispensation, which engineered the division of different African communities into ethnic groupings such as Zulu, Xhosa, Tswana and Venda. The policy thus served a political agenda, and not the advancement of linguistic capital within a language rights framework. According to Alexander (2003), the aim was to keep black people away from mastery of English, a language of access, social mobility, international recognition and power. He cautions that within the post-1994 democratic dispensation, the corollary of the Apartheid language policy is not appropriate:

> It is significant that the political class, specifically the black elite uses the pro-English argument precisely on the grounds that this may help to undermine

> the latent ethnic divisiveness of language-based mobilisation, as well as the inherited racial identities of the Apartheid and colonial past. (p. 16)

Language debates are complex, particularly for a society in transition towards democracy where language and education were used as tools of oppression. English arguably plays a ‘unifying’ role in education as it militates against categorising or dividing according to language and ethnic lines and fits in perfectly with the need for reconciliation from a divided past. However, the class has to be factored into the debate as poor children struggle with language acquisition and achievement in socially, economically and linguistically divided contexts. Chetty (2014) maintains that ‘when class replaces race as the central variable of social life, the lens through which to view the race–class struggle in South African higher education becomes clearer’ (p. 93). The democratic dispensation witnessed the state declaring 12 official languages (including sign language), but only English is used for statutory purposes. Although English is not the home language of the majority of learners, school governing bodies (SGBs), which have the power to choose the language of instruction at schools, still choose English above all the other official languages. This ‘choice’ indexes the hegemony of English and the continued marginalisation of African languages (Alexander 2003). Any official attempts at limiting the power of SGBs – such as the Basic Laws Amendment Act (Republic of South Africa [RSA] 2024) – are fiercely resisted by privileged English-medium schools as well as (historically white) Afrikaans schools and their political proxies. These stand accused of using school language policy as a continued mechanism to exclude (disadvantaged) black learners, thereby perpetuating elite closure.

Teacher education can play a significant role in enhancing achievement in literacy in language, particularly among students from poor schooling backgrounds, as well as in the training of future teachers who will return to their disadvantaged communities as qualified educators. Prinsloo and Ashworth’s (1994, pp. 125–126) recommendations from three decades ago should be considered in teacher education.

- European models of pedagogy should be disrupted.
- Creative and innovative teaching methodologies should replace transmission modes of teaching.
- Curricula should consider local and indigenous knowledges, and local writings should be included in the syllabi to disrupt the canons of knowledge or ‘settled’ knowledge.
- A multicultural ethos should be encouraged in classrooms together with new ways of language learning using translanguaging skills.
- All children should be encouraged to participate in lessons, and children’s home languages should be valued.

Academic literacy and epistemological access for Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship students

The political emancipation in 1994 saw the education landscape change dramatically. Whereas previously schools were monolingual or bilingual and predominantly monocultural, they were now open to students from a diversity of language and cultural backgrounds, as township students milled into schools they were previously excluded from. This occurrence perpetuated existing as well as spawned new challenges for epistemological access, which to date have not been successfully addressed. The drive to facilitate inclusion was also tied to novel approaches to the mediation and production of knowledge as manifested in the array of policy changes in education. This section looks at epistemological access to discourses in science education in a South African context challenged by the massification of education in the face of significant resource poverty and stark inequalities. Specifically, this section considers ways of developing academic literacy in the Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) disciplines. It focuses on core areas of digital literacy, multilingual learning, genre and the creation of a positive and enabling classroom environment to facilitate epistemological access.

Academic literacy is usefully defined as the social and cultural embeddedness of literacy practices and 'being able to use, manipulate, and control language and cognitive abilities for specific purposes and contexts' (Van Dyk & Van de Poel 2013, p. 56). It is linked to the concept of multiple literacies existing in various contexts (Gee 2008).

A significant factor in epistemological access is the capacity to accommodate different styles of learning. How do we capitalise on the different types of learning our students are endowed with? Here, determining the difference between professional and personal learning would be helpful. Professional learning engages with the mastery of new ideas, the competent processing of new information and the development of new skills. Personal learning deals with new ways of conceptualising issues, acquiring new strengths and even reviewing particular attitudes and beliefs. What must be foregrounded is that some professional learning manifests only in tandem with adequate personal learning (Caine & Caine 2010). Student learning in the classroom is optimised by the presence of three interactive elements:

- relaxed alertness in a low anxiety zone

- the planned immersion of learners in complex experiences in which the content (information, ideas and skills) is embedded in cognitively challenging ways
- the active reflection and processing of experience (Caine & Caine 2010).

In a South African context, the factors that militate against the establishment of such an environment are myriad, ranging from poorly resourced schools, overcrowded classrooms, student malnutrition and challenging home conditions, to name a few. These factors collectively accentuate student stress and demotivate learners. Seligmann (2018) suggests that creating a positive and enabling classroom by the use of positive psychology may help.

A positive approach, known as the 'positive effect', has demonstrated improved cognition in learners and is associated with:

- episodic as well as working memory
- creative problem-solving
- social interactions (being helpful and sociable)
- appropriate decision-making
- added flexibility in thinking
- increased verbal fluency in teenagers (Ashby, Isen & Turken 1999).

Critical to this is the development of intrinsic motivation, where learners have the opportunity to ask their own questions and deal with issues of personal interest. Learners need opportunities to analyse and sometimes research the science (STEAME) content in question, rather than have the content mediated in a teacher-dominated narrative, with the risk of learner passivity.

Additionally, learners require contexts that allow them to link new material to existing knowledge; participate in active learning and engage with learning material; receive strategic coaching, thoughtful guidance and rational explanations; and observe and learn from the competent performances of others. Most importantly, learners should be able to use the material as a precursor for action in the real world.

Epistemological access can be strengthened by requiring learners to reflect upon their learning tasks. This may be encouraged by questions in the science classroom such as:

- Could you explain what you are doing?
- Why did you choose to do it this particular way?
- How do you explain this?
- What would happen if you changed a particular aspect (such as …)? (ed. Bold 2011).

This approach reinforces the notion that one of the most powerful tools to develop higher-order thinking skills is to use student talk as the centre of classroom instruction. Critical to productive teaching and learning is the scaffolding of student talk to mediate higher-order thinking that entails deciphering texts, drawing comparisons, synthesising and evaluating texts, looking for evidence to validate claims, examining the authority of the writer to express ideas and interpretations, and linking new knowledge to prior learning. Epistemological access is therefore predicated on increasing student agency, active learning and granting more responsibility to students to take control of their learning – in other words, enabling self-directed learning (De Beer 2016).

The student profile worldwide has substantially evolved in the 21st century, particularly in urban areas. Students are increasingly using screen-based, digital technologies to locate and transmit words, images, video and sounds as they engage in meaning-making, identity connections and social networking experiences. Consequently, they come to school with experiences, interests, cognitive assets and defined skills that uniquely enable learning and social interaction in classrooms (Mahiri 2011). Many students come to school with a vast array of experiences, interests and discreet skills – a complex of resources for meaning-making – that are mediated via digital texts and tools. The ubiquitous cell phone is a case in point with its diverse capabilities for accessing written texts, voice recordings, music, pictures, video, TV, the internet, GPS, clocks, calendars, calculators and games (Mahiri 2011). A rich variety of applications are available for added personalisation and performance of smartphones, and many more innovations and rapidly evolving media platforms are used for communication, pleasure, work and social networking. These reflect a new impetus to literacy that offers multiple resources for meaning making and identity construction for youth and adults (Mahiri 2011).

Understandably, Lankshear and Knobel (2011) argue that page-based texts and their corresponding instructional practices do not compete well in what they term the 'attention economy'. Epistemological access may therefore be enhanced by teachers moving from an exclusive use of page-based learning to innovative use of podcasting, blogs, digital photography, video and Google Maps, among others. In the move from the page to screen, textual mediums offer a variety of resources for meaning-making – mediums that are highly accessible, interactive, portable and interchangeable. These qualities stem from digital media's capabilities to include graphics, moving images, sounds, shapes and other forms of texts into computable data (Manovich 2001). Essentially, new media enable new literacies. Moreover, networking allows access to knowledge from other people, texts and tools that enable a swift acquisition of ideas.

Chavez and Soep (2005) suggest that the following can improve student engagement with computer-mediated learning: (1) collaborating on media projects, (2) inquiry as a principle form of learning, (3) strategic involvement to incorporate comprehensive perspectives into the inquiry and influence social change and (4) distributed accountability among all participants in the production of media projects. Using multimodal avenues of learning is a recognition that meaning and knowledge are built up through various modalities (not just print) in conjunction with a semiotic understanding that learning involves interrelations with and across multiple, complex sign systems.

Despite classrooms being a site of multilingual interaction, teaching practices are mostly monolingually oriented in most learning institutions. Teachers should focus less on linguistic errors in a multilingual classroom and more on academic potential, resisting the urge to conflate language use with intellectual ability. A multilingual class can gradually evolve through exposure, immersion and engagement. Practitioner experience suggests that teaching is mostly content driven, and the pressure to teach to an examination in lieu of focusing on understanding and ensuring cognitive development and epistemological access takes precedence. Hull and Rose (1990, p. 296) critique 'the desire of efficiency and coverage', noting how this focus limits rather than promotes students' 'participation in intellectual work'. Students whose mother tongue is not English are often 'othered' and wrongly stereotyped in deficit terms. Cumming (2012) makes clear that students' sense of engagement or alienation has less to do with the content than with the pedagogical approaches and conditions that manifest in the curriculum. The above-mentioned deficit thinking blinds us to the logic, intelligence and richness of students' processes and 'funds of knowledge' (Moll 2019) and the affordances of a multilingual repertoire that learners bring with them. Promoting minority or marginalised languages would enhance epistemological access by facilitating inclusion and enabling students to access learning in a linguistic repertoire of choice. Importantly, a study by Jessner and Kramsch (eds. 2015) suggests that metalinguistic awareness enhances metacognitive skills and is a rich resource that teachers could potentially exploit.

Canagarajah (2020, p. 122) defines 'literacy development as the process of becoming familiarised with the technical language and the recurring phraseology as well as the genre conventions that shape the production of disciplinary texts'. This perspective is apt in the teaching and learning of science and other STEAME discourses. It is a process by which learners become enculturated in the beliefs, shared values and epistemologies of scientific discourses. Academic literacy for epistemological access in the sciences is consequently not the sole preserve of English teachers but should be purposefully taught across the curriculum. Consequently, teachers require training in 'multifaceted aspects of specialized language forms and practices, spanning microlevels of vocabulary, orthography and morpho-syntax as well as macrolevels of registers, genres, styles of reasoning and academic conventions' (Schleppegrell & O'Hallaron 2011, p. 7).

As the informal registers of home and community differ from the formal discourses of the school curriculum, students require carefully nurtured scaffolding to productively participate in science genres. Academic language usually contains words that are suitable for formal speech and writing but may not be commonplace in everyday discourse. Curry and Hanauer (eds. 2014) make the point that when students are assigned to write in science genres, they often are unaware of the structure, conventions, formatting requirements, vocabulary and content (what to include and exclude) that would make their writing acceptable for a particular discipline. To compound matters, the specialised vocabulary that they need to control (along with associated abbreviations and acronyms) becomes a formidable task that makes epistemological access challenging. Consequently, the genres of science, mathematics, engineering and technology should be taught to facilitate epistemological access. Learners should be trained to acquire formal genre structures and schemata and to become aware of the intended audience(s) and communicative purposes expected with a specific genre. This should be done with the foreknowledge that the social contexts in which the science texts are produced constrain the choice of textual features and shape writing practices. Writing in the science genres then becomes a social, personal, cognitive and reflective practice.

While the scaffolding of scientific discourse remains paramount, Oyoo and Simeon (2015) draw attention to learner difficulties with the *non-technical* language use in the science classroom, arguing that understanding everyday or non-technical terms used in a science context is as crucial as knowledge of technical terms. The authors distinguish between three different types of everyday words found in science texts, viz. logical connectives (e.g. 'since' and 'conversely'), meta-representational terms (e.g. saying verbs such as 'define', 'suggest' and 'explain') and non-technical words that require contextual proficiency to be understood, that is, that have a science-specific contextual meaning. In their mixed-methods study, the authors found that Grade 12 Physical Sciences learners had difficulty understanding everyday words such as 'sensitive' or 'spontaneous', in a science context (2015, p. 53). Moreover, interviewed teachers were reportedly 'not aware that everyday words could be misunderstood by learners' (2015, p. 59). The implications of this finding are potentially far-reaching and should be used by science teachers, departmental officials and university science teacher educators to enhance academic literacy for epistemic access. They should also inform the approaches and materials of those committed to mother-tongue-based bilingual or multilingual STEAME education (see below).

Epistemological access in STEAME education, then, would benefit from teachers and curriculum planners reflecting upon the following: To what extent can social contexts effect academic literacy development? What literacy development stages does a novice writer need to progress through to deftly use language in those social contexts? What cognitive processes and responses are activated when a novice writer is, either intentionally or unintentionally, exposed to the language and rhetorical conventions of academic texts? How can past writing experiences and prior genre knowledge help novice writers to engage successfully in writing? What are the implications of understanding discourse as text, writer-reader interaction and discourse-context relationships? When and how do you use a personal voice in an academic text? How can a writer's identity be constructed in academic writing? What are the institutional conditions that facilitate and constrain discourse and rhetorical conventions? (eds. Hyland & Shaw 2016).

■ Pedagogical translanguaging

In South Africa, STEAME education is in crisis as manifested by the poor results of learners in the TIMMS, SACMEQ and National Senior Certificate (NSC) standardised assessments. Despite an overall upward trajectory in the NSC pass rate in recent years, learner attainment in Mathematics and Physical Sciences remains low. For example, while the overall pass rate in the 2022 NSC Physical Sciences exam was above 80%, fewer than one in three learners (63 457 of 209 004, or 30%) achieved 50% or above, while only 17% of learners scored at least 60% (Department of Basic Education [DBE] 2023). These thresholds are used by many universities as a criterion for admission to science degrees. Furthermore, they should be read through the prism of the bimodal distribution of achievement that continues to characterise the schooling system.

Three decades into the officially multilingual dispensation, it is an indictment of the education sector at large that the NSC must be written in either English or Afrikaans, as was the case under Apartheid, and cannot be taken in an African language. In acknowledgement of the language factor in learner performance across the curriculum, the Department of Basic Education continued (until 2022) with the Apartheid-era practice of giving a 3% 'language compensation' per subject to NSC candidates writing the content subjects in English as a Second Language (Western Cape Education Department [WCED] 2017), that is, in a non-mother-tongue.

This was little more than a sop to African-language speaking (i.e. black) learners, however, and could not compensate for the systemic disadvantage of having been denied the right to mother-tongue-based education from Grade 4 upwards. Or as the WCED put it:

> National Senior Certificate results indicate that learners with limited English proficiency and inadequate cognitive academic language skills are underachieving across the curriculum. This point highlights the fact that the language of instruction and academic achievement are directly linked. Therefore, a learner's language ability has a huge impact on results as all content areas are embedded in language. (n.p.)

The DBE's answer was to introduce the teaching English across the curriculum (TEAC) initiative in 2013–2014. It presumes the continued dominance of English as the language of learning and teaching (LoLT) and advocates maximal exposure to English across all subjects. The development of a manual with exemplars of lesson activities was followed by in-service training of teachers, officials and university academics. Teachers across all subjects are encouraged to have print-rich classroom environments, do reading and writing, and teach the register of assessment. In its interpretation of the TEAC, the WCED requests schools to:

> [*R*]educe the amount of code switching and code mixing in order to ensure maximum exposure to the LoLT as the language of assessment. In the case of a large number of schools in this province, this would refer to English. (WCED 2017)

It is unfortunate that the call to minimise code-switching and code mixing, while seemingly self-evident, rests on the questionable assumption that learners' mother-tongue or multilingual resources are irrelevant to their learning. What has since become known as pedagogical translanguaging (cf Probyn 2015) can, if utilised with awareness, improve the understanding of STEAME in bi-multilingual contexts. Translanguaging refers to teaching approaches that involve the intentional and planned use of students' multilingual resources in language and content subjects; this means that more than one language is used in teaching to benefit students. As Canagarajah (2018:40) explains, 'translanguaging is the ability of multilingual speakers to switch between languages, treating the diverse languages that form their repertoire as an integrated system'. The boundaries between the more traditional terms codeswitching and codemixing, on one side, and the newer 'translanguaging' are still being defined. Rahman and Singh (2021) note overlaps between code switching and translanguaging, and explain codeswitching in linguistic terms whereas translanguaging focuses more on fundamental sociolinguistic and ecological aspects. Hornberger and Link (2012) see translanguaging as a way of understanding how different language speakers behave in multilingual contexts, while .in codeswitching speakers are assumed to use two separate grammatical structures in one conversation. Although both codeswitching and translanguaging focus on language use which entails conversions, interference and / or borrowing of items, translanguaging extends its scope beyond crosslinguistic interference to how multilinguals intertwine linguistic features structurally or linguistically assigned to a specific language (Garcia 2009).

In the past decade, a growing number of studies have investigated how multilingual learners access knowledge from both home- and school-based, informally and formally taught concepts as they develop proficiency in mathematics and science processes.

Liddicoat (2016) argues that English as Medium of Instruction as a teaching principle obstructs the use of different languages in HE classrooms, especially in Asian countries such as China, Japan and Malaysia. Rahman and Singh (2021) investigated English-medium university Science, Technology, Engineering and Mathematics (STEM) teachers' and students' ideologies in the construction of content information through translanguaging in Bangladesh. They brought to light the discrepancies in the use of English at different levels, that is between macro-level English-only language policy adoption driven by contemporary ideologies associated with English and micro-level stakeholder's ideologies of translanguaging in STEM (or STEAME) pedagogy. They argue for a change in how we view language practices and the imperative to be inclusive or embrace the linguistic rights of all in higher education language policy.

Studies conducted in higher education STEAME contexts have shown translanguaging to be an important linguistic and pedagogical resource. According to Wei's (2018) study of a Bangladeshi university, the ideology of STEM teachers and students goes beyond linguistic and communicative borders in using multiple languages such as English and Bangla for teaching and learning through different modalities such as textbook and presentation slides.

Most rural and township learners in South Africa learn science in English even though it is not their home language; learners' poor English proficiency restricts them from accessing knowledge across the curriculum. As we point out above, the discourse of science on its own poses challenges for learners as it contains many unfamiliar words that learners need to master. Learning science also involves a cognitive shift from every day common sense understanding of how the world works to a scientific view of the world (Probyn 2015:2). The shift is very difficult if a learner is not familiar with the language used. Teachers' response to learners' poor English proficiency is to switch to learners' home language for a variety of cognitive and affective reasons. What transpires from these practices is that learners are able to orally communicate in two languages while reading, writing and assessment are conducted in English (Setati, Adler, Reed & Bapoo 2002). If translanguaging into and from learners' mother tongues is limited to lesson presentations and oral interaction and does not extend to written assessments or materials, it remains an insufficient compensatory measure. 'Codeswitching /codemixing' then becomes an easy scapegoat for poor performance, when the real issue is the lack of fit between home and school language (varieties).

In a bilingual context, developing learners' knowledge in their home language and then transferring this understanding to the LoLT seems to be advantageous (Cummins 2008). Thus learners' home language could be used for explanatory talk, both in group discussions or in teacher-led whole class discussions. The conscious use of translanguaging enables working on understanding in learners' home language and then transferring that understanding to English, and is usefully regarded as a further aspect of pedagogical bridging discourse (Probyn 2015). In fact, studies show that learners who understand different languages have always resisted monolingual policy prescriptions in favour of fluid, versatile and mobile discursive resources to accomplish their classroom communicative tasks (Hornberger & Link 2012). Similarly, Nhongo and Tshotsho (2019:67), in their study on translanguaging as an instructional method in rural and urban high schools, confirm that translanguaging holds notable benefits. Learners have to develop an understanding of the (STEAME) concepts, which is achieved through translanguaging. The purpose of translanguaging is to develop conceptual knowledge through the home language, and to enable learners to transfer concepts from the home language to the LoLT. In this way the home language would have been used as a resource towards cognitive development. Setati et al. (2002) cite the challenge faced by teachers in using the method of translanguaging that translanguaging is used not only to bridge the gap between learners' understanding in their home language and the LoLT (English) but also to overcome the barrier between regular discourse and scientific or academic discourse. These insights regarding bilingual science teaching have been usefully explored in relation to decolonial theory by Tyler (2023).

A relatively recent language ideological turn is of relevance to the pedagogical translanguaging debate. The last two decades have seen a challenge from within applied linguistics research to inherited views about the nature of 'language' and of multilingualism. A growing body of African scholarship into linguistic diversity has begun to question the concept of discreet and separable languages as a colonial European import. In brief, the argument is that the traditional notion of 'languages' as countable, bounded, separate entities – each with their own vocabulary, syntax, phonology, morphology and orthography – is sociolinguistically indefensible. The critique extends to terms such as mother tongue, first language, additional language and additive bilingualism. Makoni (2003), for instance, critiqued the country's language-in-education policy for schools (Department of Education [DoE] 1997) which, it is claimed, does the nation a disservice for couching multilingual education in multiple monolingual terms and is therefore politically-culturally suspect from the start – a hangover of colonial-Apartheid separatist thinking (see Makoni 2003). McKinney (2017), similarly, attributes the lack of implementation of the policy, at least in part, to its (flawed) understanding of multilingualism. Instead, the argument goes, it would be more accurate to speak of *languaging* in translanguaged or heteroglossic terms that consider the fluidity of everyday spoken varieties and to recognise the distinctively African manifestations of multilingualism. Central to the argument is the need for a decolonised Africa-centred conception of 'convergences of multilingualisms and multiliteracies' (Mwaniki 2018, p. 27). Makalela's (2018) coinage of *ubuntu translanguaging,* in terms of which no single language is complete without another, indigenises the translanguaging concept and speaks particularly to linguistically diverse African postcolonial contexts such as Gauteng province or Limpopo province where speakers grow up with mutually overlapping language varieties and linguistic 'fuzziness'.

While such new ontologies contribute to our understanding of African sociolinguistics, they also hold potential dangers within the context of bilingual/multilingual education. Desai (2013), for example, pointed out that the celebration of multilinguality potentially disempowers African languages and their speakers by implying that African languages are only good enough for the (linguistic) marketplace but not for literacy and schooling – leading to default to the English position. Heugh and Stroud (2020) warn of the uncritical adoption of the Northern-influenced critique of (additive) bilingual educational models that were developed in South Africa in the transition to democracy. They aver that the adoption of the fluidity-focused translanguaging paradigm may have the unintended consequence that:

> *[M]*ost students in post-colonial settings, are (or will be) at risk of being denied access to the standardised variety of written and spoken languages that open doors to higher education and high-level employment opportunities. By default, this will have the same effect of marginalising and disempowering students that has been associated with colonial and discriminatory policies such as in Apartheid education. Quite simply, unless students can access and gain proficiency in a written language variety of high status, such as English, and use it in the mainstream economy and avenues of power, their life chances will remain limited, as they were during Apartheid and in colonial contexts elsewhere. (Heugh & Stroud 2020, p. 220)

Instead, Heugh and Stroud (2020) invoke Heugh's older concept of functional multilingualism, based on the language-as-resource paradigm, to describe the simultaneous need for people to control both 'horizontal communicative practices of conviviality' and 'vertical "standardised" written variety of language' for high-end educational purposes. The acceptability of functional multilingualism comes with the caveat that these high-end purposes are in principle not limited to English but are extended to the official African languages. Such recognition also considers that language curricula in schooling systems are currently divided into bounded subjects and that epistemological access to the powerful schooling genres is provided through literacies in the standard(ised) variety of the language(s) of learning and teaching (cf Kerfoot & Van Heerden 2015).

While the Anglonormative orientation (McKinney 2017) of South Africa's education system is not unusual in a post-colonial African context, there is growing international recognition that a socially just and meaningful access to education depends on the inclusion of learners' linguistic resources. A 2003 UNESCO report distilled 50 years of research on language and education into two principles:

- support for 'mother tongue instruction as a means of improving educational quality by building upon the knowledge and experience of the learners and teachers' (p. 31)
- support for '*bilingual* and/or *multilingual education* at all levels of education as a means of promoting both social and gender equality and as a key element of linguistically diverse societies' (p. 32).

The country's *de facto* language regime is thus out of synchrony with research globally that emphasises multilingualism as a potential educational resource to be utilised, not problematised or rejected (cf Lo Bianco 2001). That is, students' linguistic repertoires and 'light funds of knowledge' (Moll 2019) should form the basis of further language learning and indeed of all learning. Far from coming at the expense of acquiring international power languages such as English, mother-tongue education (where feasible) is identified as a necessary pre-requisite or co-determinant for this endeavour. This holds particularly for speakers of minority-status languages and of non-dominant varieties of powerful languages (Benson & Kosonen 2021), for example predominantly working-class dialects such as Kaaps/Afrikaaps.

In this regard, the planned introduction of mother-tongue-based bilingual education (MTBBE) by the national DBE (Motshekga, 2023) is a progressive step in realising the country's language-in-education policy for schools (DoE 1997). The proposed extension of mother-tongue-based education to Grade 4 and upwards under the moniker 'mother-tongue-based bilingual education' follows a successful pilot study in Eastern Cape primary schools over the previous decade. A PhD study of an aspect of the pilot showed improved results for Mathematics, which was taught and assessed mother-tongue-based-bilingually (in isiXhosa and English) up to Grade 6, with benefits for results in science (Mbude 2019). The proposed introduction of a national MTBBE Grade 4 assessment in 2025 is particularly significant and is accompanied by the amendment of the LoLT concept to that of LoLTA – the language of learning, teaching and assessment. Reassuringly, the Ministry of Basic Education of the incoming Government of National Unity (June 2024) has voiced its support for MTBBE.

The MTBBE initiative, while research-based, has implications for the education sector at large, particularly for those working in or servicing primary schooling. Bilingual learning support materials (cf ISayensi yethu, by CMDR & bua-lit & vliruos), as well as advocacy materials will be required. Teacher education for the Intermediate Phase – both in-service and pre-service – will have to adapt quickly, particularly in the form of accredited short courses in multilingual pedagogy across the curriculum (incorporating translanguaging) as well as re-calibrated bilingual Bachelor of Education (BEd) degrees (Intermediate Phase), initially mainly for students qualifying as mathematics and science teachers.

■ Conclusion

This chapter has explicated South Africa’s language-in-education policy from a sociology of language perspective, unpacked questions of academic literacy and epistemological access in STEAME education, and discussed translanguaging as a teaching and learning (classroom) resource and as a new ideological ‘turn’. It has also drawn attention to new language policy developments and the implications of adopting a heteroglossic approach to multilingualism.

Chapter 7

Engaging pedagogies for self-directed learning

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Abstract

South Africa is well known for its rich cultural, ethnic, linguistic and ecological diversity, contributing significantly to its wealth of indigenous knowledge (IK). However, the country must integrate IK more effectively into its educational system. Many school teachers struggle with incorporating IK into curriculum themes, highlighting the need for a 'pedagogical laboratory' to teach IK effectively. Similarly, teacher education should rethink pedagogical orientation to enhance students' competence in imparting scientific knowledge and assimilating IK systems into curricula. The affective domain of learning is often overlooked. Movements such as #ScienceMustFall, #RhodesMustFall, and #FeesMustFall have brought attention to the demand for 'decolonisation' and 'transformation' in South African higher education institutions. Through the lens of embodied, situated and distributive cognition (ESDC), it is critical to foreground students' pre-existing knowledge, backgrounds and environments in the learning process. This chapter weaves ESDC into a conceptual framework to enhance Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education with 'I' representing innovation; 'A' embodying art, emphasising creativity and expression; and 'E' signifying entrepreneurship through engaging pedagogies for self-directed, holistic learning and affective development. It is underpinned by the person-process-context model for self-directed learning, incorporating engaging pedagogies such as problem-based, cooperative and inquiry-based learning. The framework also emphasises IK and multiple intelligences to support self-directed learning and address the relevance of science in the 21st century.

Introduction

This chapter argues that the epistemological border crossing between indigenous knowledge (IK) and Western science creates an effective social environment. Student interests should drive instruction to establish an environment (Dewey 1938). Recognising the diverse characteristics of learners, education should appreciate their multiple intelligences (MIs). The context of the school and the learners plays a crucial role in learner performance. Therefore, teaching should shift from teacher-centred pedagogy to learner-centric approaches. Many classrooms need to encourage the self-directed learning (SDL) competencies of students.

The chapter provides insights into how engaging pedagogies such as inquiry-based learning (IBL), cooperative learning (CL) and problem-based learning (PBL) promote SDL. Inquiry-based learning is pivotal as it encourages collaboration among learners, fostering the creation of new knowledge while honing critical thinking, creative problem-solving and discovery skills through active engagement, exploration and reflection (Alberta Education 2010, p. 19). It empowers individuals to delve deeper into concepts, enabling the application of knowledge in real-world contexts and thereby instilling lifelong learning practices. Teachers need to recognise that teaching and learning should transcend mere data accumulation, aiming instead to foster the creation of practical and applicable knowledge beyond the classroom. The implementation of IBL methodologies facilitates this transition towards real-world application.

Cooperative learning aligns with SDL, as students accept responsibility for learning within group dynamics. The fundamental elements of CL entail positive interdependence, individual accountability, face-to-face promotive interaction, social skills and group processing skills (Johnson & Johnson 1998, pp. 70–71). It is imperative to nurture social interaction and analytical thinking skills and to harness diverse MIs to solve problems effectively. This engaging pedagogy for SDL is advocated within a context that recognises the student (person), the teaching–learning transaction (process) and the learning environment (context), particularly in the South African context.

■ Conceptual framework for enhancing Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education

A conceptual framework represents the expected relationship between different variables (Tamene 2016), thereby defining the objectives of the research process. It maps out how these variables interconnect to form coherent conclusions. Constructed from a network or plane of interrelated concepts, the framework provides a comprehensive understanding of a given phenomenon (Jabareen 2009). This chapter's conceptual framework focuses on enhancing Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education in South Africa through engaging pedagogies for SDL, holistic learning and affective development. It is underpinned by Hiemstra and Brockett's (2012, p. 158) person-process-context (PPC) model of SDL.

The framework encourages students to work collaboratively, communicate effectively, think critically and develop essential 21st-century skills, while taking charge of their own learning process. It also emphasises integrating IK into the curriculum to address the relevance of science and society. While Western science offers a comprehensive perspective on global contexts, IK provides deep insights that are grounded in local, culture-specific experiences. The framework recognises the importance of the affective domain of learning and the need for pedagogical approaches to impart scientific knowledge effectively, particularly in South Africa's diverse cultural, ethnic, linguistic and ecological richness. This approach engages the affective domain by incorporating learners' IK and lived experiences. It raises awareness of science's role in society and offers learners a nuanced understanding of science's nature and principles. By integrating relevant IK into curriculum themes, science education can become more thought-provoking, engaging and meaningful for learners (Abah, Mashebe & Denuga 2015). This approach can lead to improved performance (Jacobs, De Beer & Petersen 2016). An often-overlooked factor contributing to poor performance in science is the neglect of certain key aspects. The affective domain, which plays a crucial role in human thinking, is frequently neglected in science education.

Learning is inherently connected to its context and cannot occur in isolation, as emphasised by the principles of embodied, situated and distributed cognition (ESDC). Learning is inherently connected to its context and cannot occur in isolation, as emphasised by ESDC principles. This interconnected nature of learning is particularly evident where IK and Western ways of knowing converge, forming what can be understood as a cultural interface. These cultural interfaces, while sometimes contested, also serve as spaces where different knowledge systems can collaborate synergistically. The theoretical basis of the PPC model is grounded in the principles of SDL as outlined by Knowles (1975). According to Knowles, SDL involves individuals taking the initiative to assess their learning needs, establish learning goals, identify appropriate resources, implement effective strategies and evaluate their learning outcomes, either independently or with support.

This chapter emphasises SDL's importance, recognising it as essential for adequate preparation in a complex 21st-century world. Morris (2019) frames SDL as a pathway towards empowerment for purposeful, individual and developmental change. Self-directed learning has become an integral part of work and life, and research indicates that countries fostering a culture of SDL are more likely to prosper economically.

■ Person-process-context model for self-directed learning

To support self-directed students, it is essential to recognise the person, the process and the context (Brockett & Hiemstra 2014). The PPC model, as proposed by Hiemstra and Brockett (2012), provides a framework for understanding the interplay between the individual learner (person), the teaching–learning transaction (process) and the learning environment (context). This model underscores the importance of considering individual characteristics, the teaching–learning transaction and the learning environment in the learning process.

Understanding the person in the person-process-context model

It is essential to understand the person to make the process effective within the context of the PPC model. The person refers to the characteristics of the individual, such as creativity, critical reflection, enthusiasm, life experience, motivation, previous education, resilience and self-concept in Science, Technology, Engineering and Mathematics (STEM) education, among other characteristics influenced by the context of students (Hiemstra & Brockett 2012). Despite the aim of the South African school curriculum policy (i.e. Curriculum and Assessment Policy Statement [CAPS]) for inclusivity, it overlooks personal characteristics shaped by the person. Integrating IK within curricula holds the prospect of creating a context for students to identify with their cultural roots, helping them express their identity in a unique space provided by process and people leveraging IK for entrepreneurial opportunities.

Understanding the process in the person-process-context model

Hiemstra and Brockett (2012, p. 158) describe the process as 'involving the teaching-learning transaction, including facilitation, learning skills, learning style, planning, and evaluating abilities, teaching style, and technological skills'. Engaging pedagogies are the connection between the context and the process. To support self-directed students, it is essential to recognise the person, the process and the context.

Understanding the context in the person-process-context model

The environmental and socio-political climate has continuously influenced the South African education system for three decades post-democracy. Factors such as the prevalent learning culture (e.g. behaviourism grounded in traditional 'chalk and talk' pedagogy), the learning environment (including issues such as overcrowded classrooms and insufficient resources), and race and class disparities are pivotal in delineating the stark divisions within the education system. Moreover, this schism extends to educational approaches, notably in science education, where education is bifurcated into high-performing (approximately 20%) and low-performing (approximately 80%) schools. Urban, affluent schools consistently demonstrate better academic outcomes than their rural counterparts, highlighting a persistent educational divide (Jansen 2019). High-performing and affluent school priorities guide pedagogical orientation. In contrast, a prevalent trend across former township schools involves a direct pedagogical approach, typified by a teacher-directed learning process (Ramnarain & Shuster 2014), marginalising students' autonomy.

Brockett and Hiemstra (2012, p. 158) contextualised this concept of context, encompassing elements such as the socio-political climate, cultural dynamics, power structures, financial constraints, gender dynamics, learning climate, organisational policies, political milieu, race dynamics and sexual orientation within the educational landscape. Understanding these contextual elements is crucial in comprehending why context cannot be ignored when SDL underpins the conceptual framework.

■ Engaging pedagogies for self-directed learning

Pedagogies serve as the bridge that connects the three elements of the PPC model. They are the instructional methods and strategies used to engage the individual learner (the person) within a specific learning process (the process) situated in a particular context (the context). By carefully selecting and implementing pedagogical approaches such as PBL, IBL and CL, teachers can optimise the alignment between the individual learner, the learning processes and the educational context, creating a more engaging and meaningful educational environment. Furthermore, by integrating SDL as a process that nurtures autonomy and acknowledges the diverse intelligences outlined in MI theory, teachers can enhance the holistic educational experience within the PPC framework. In doing so, they create an environment that aligns individual learners, learning processes and contexts, encouraging learners to take charge of their learning journeys and making education personalised and dynamically engaging.

■ Cooperative learning as an engaging pedagogy

Unlike competitive and individualistic learning approaches, CL necessitates students to collaborate towards shared objectives (Johnson & Johnson 1998). Cooperative learning aligns with SDL, as students assume responsibility for learning within group dynamics. The fundamental components of CL, as outlined by Johnson, Johnson and Smith (1998, pp. 70–71), encompass the aspects as listed below.

1. *Positive interdependence*: Students participating in CL perceive their connection to their peers in the learning process. Each person's effort should benefit others, as the others' work benefits him/her. Mutual learning goals are essential to achieving positive interdependence, which can be further reinforced by implementing joint rewards, allocating resources equitably and assigning complementary roles.
2. *Individual accountability*: Students are individually responsible for and held accountable for their portion of the group's work. They may be tested individually, randomly selected to represent the entire group or have each learner explain what they have learned from a classmate. The quantity and quality of each learner's contribution to the group work will be assessed and evaluated.
3. *Face-to-face promotive interaction*: Individuals can support each other's success by offering help, encouragement, support and praise. Through such interactions, students can further each other's learning by explaining problem-solving methods, discussing concepts, sharing knowledge, linking current and past learning, and more. Promoting face-to-face interaction among students can be achieved through (1) peer accountability; (2) the ability to influence each other's thinking and conclusions; (3) social modelling, offering social support; and (4) providing interpersonal rewards.
4. *Social skills*: Students learn leadership, decision-making, communication and conflict management skills to ensure that learning occurs effectively in small groups during CL. They also acquire education in leadership, decision-making, communication and conflict management skills to ensure effective learning within small groups during CL sessions. These skills will be developed through CL as a teaching–learning strategy. However, students face challenges working in groups with limited social skills. Therefore, as a learning facilitator, the teacher plays a pivotal role in offering opportunities for developing social skills to ensure the effectiveness of CL processes.
5. *Group processing*: Students must identify, define and resolve their problems to collaborate effectively. Group members should regularly discuss how well they work together, maintain strong relationships and progress towards their goals.

Implementing CL, representing SDL principles, offers a robust framework for advancing education by placing students in control of their learning process within a collaborative group dynamic (Johnson & Johnson 2009). As we delve into the concept of interdisciplinary exploration through CL, it is essential to recognise the established effectiveness of this pedagogical approach. Acknowledged across various academic disciplines and educational levels (Pelnēna & Medveckis 2022), CL, rooted in social constructivism, not only promotes essential SDL skills such as critical thinking, communication and collaboration but also aligns seamlessly with contemporary educational paradigms that emphasise learner agency and the cultivation of lifelong learning skills.

Interdisciplinary exploration through cooperative learning

Cooperative learning, a pedagogical cornerstone where students collaborate to achieve shared learning goals, is widely acclaimed for enhancing educational outcomes and nurturing vital life skills (Johnson & Johnson 2009). In the context of STEAME education, CL emerges as a dynamic conduit for interdisciplinary exploration, aligning seamlessly with the collaborative skills essential for 21st-century education.

Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education thrives on the interconnectedness of its components, encouraging students to perceive and experience the synergies among science, technology, engineering, arts, mathematics and entrepreneurship. This interconnected worldview is conducive to holistic learning and aligns with the demands of a rapidly evolving global landscape. Cooperative learning is fertile ground for realising interdisciplinary exploration within STEAME education. For example, envision a physics project where students from diverse disciplines converge to design and construct a functional solar-powered device. In this collaborative venture, each learner contributes unique expertise, creating a microcosm where the principles of physics, engineering and technology intertwine. Furthermore, this taps into specific content, directly affecting their community (and the country as a whole), which faces a continuous challenge with electricity delivery. This connects the interdisciplinary project to a real-world challenge, emphasising the practical implications of the students' collaborative efforts within their community.

Problem-based learning as an engaging pedagogy

Problem-based learning is a student-centred teaching methodology driven by open-ended, ill-structured, real-world problems in groups (Hmelo-Silver & Barrows 2006). It involves students engaging in a rigorous, extended process of asking questions, finding resources and applying information to develop realistic solutions. Problem-based learning encourages students to take initiative, build higher education and career readiness skills, and provides a feeling of empowerment. The teacher is a facilitator (Pawson et al. 2006, pp. 104–106), and students work in small groups to research the problem and formulate workable solutions (Maurer & Neuhold 2012, pp. 2–3). Compared to a traditional approach to teaching, PBL aims to develop students' SDL skills and knowledge construction (instead of knowledge transmission) based on students' prior knowledge.

Barrows (1996, p. 5) compiled a list of six characteristics that define effective PBL:

1. student-centredness
2. learning in small groups
3. teacher in the role of facilitator
4. an authentic problem presented at the start of the learning process
5. a problem serves as an instrument for discovery
6. learning of new content by SDL.

These characteristics emphasise the importance of active student engagement, collaboration and real-world problem-solving. By adhering to these principles, teachers can design PBL experiences that promote deeper learning and the development of essential 21st-century skills. The alignment of these characteristics with the principles of SDL further highlights the potential of PBL to empower students to take charge of their educational journeys.

Students today face a difficult, uncertain and complex future, and customised learning opportunities and methods may likely be the norm where students have responsibility for and control over their learning. The scenario described may be a critical underlying factor for PBL. A deeper level of learning is achieved when students apply classroom knowledge to real-world challenges and actively engage in projects that require sustained collaboration and involvement (Barron & Darling-Hammond 2008, pp. 3–8). Active and collaborative practices substantially influence student performance more than other variables, including students' backgrounds and academic struggles. Additionally, students demonstrate tremendous success when instructed on what and how to learn. Despite these benefits, successfully implementing the problem-based approach requires lecturers to meticulously design activities aligned with students' interests, needs and the curriculum. These innovative learning methods challenge the traditional 50-min classroom period, prompting consideration of alternative scheduling strategies (Scott 2015, pp. 5–6).

It is noteworthy that PBL has roots in the works of Kilpatrick (1918) and Dewey (1938). It currently also receives scholarly attention among those who believe it has the potential to engender robust knowledge-building for action. However, scholarly literature also suggests that 'careful research is needed to understand if and how these potentials may be realized' (Hmelo-Silver 2004, p. 261).

Problem-based learning and teaching

Problem-based learning constitutes an integral component within the spectrum of experiential learning methodologies. In this regard, the literature sheds light on converging evidence of PBL emanating mainly from case studies, pre–post tests and quasi-experimental designs, significantly less from controlled experiments. Much research on PBL explores the construction of knowledge, problem-solving and SDL, and there needs to be more work on motivation and collaboration. A research agenda for PBL should carefully examine these facets. It would be naïve to assume that the medical education model of PBL can be directly applied to other settings without considering the need for adaptation to students' local contexts, goals and developmental levels.

Literature also suggests a great need for evidence-based instructional strategies demonstrating which facets of PBL are essential for particular outcomes so that teachers can make informed choices in adapting PBL to their particular contexts. For example, in more diverse settings, possible barriers include insufficient and insufficiently trained facilitators; learning to facilitate effectively is an essential undertaking in PBL, and an appropriate PBL teaching and learning structure may be vital in supporting specific PBL goals.

Crucially, the role of technology in producing discipline-specific PBL also warrants due consideration, especially when lecturers in their various disciplines need assistance with instructional design. The System for Technology-Enhanced Pedagogy (STEP) system is an integrated system with video cases of classroom instruction, a multimedia textbook, a collection of problems, an interactive whiteboard and an activity framework that leads students through PBL and instructional design.

Problem-based learning and participatory pedagogies

Participatory pedagogies involve learning and teaching methods that leverage digital media and participatory cultures and actions. These pedagogies are often intertwined, crossing disciplinary boundaries and existing beyond traditional structures, making them difficult to identify and define (as shown in Table 7.1). Their informal nature can lead to challenges in understanding their impact and value on education, culture and identity.

Participatory pedagogies, as depicted in Table 7.1, demonstrate how PBL can be enhanced by integrating various media and collaborative approaches. Teachers, by employing these strategies, can create more engaging and effective learning environments (Savin-Baden & Bhakta 2019). These environments not only encourage but also necessitate

TABLE 7.1: Forms of participatory pedagogies in problem-based learning.

Forms of participatory pedagogy	Definition	Key authors
New media	Media at the intersections of books, television and radio with interactive media and social networking	Ito et al. (2010)
Producers	Collaborative and continuous building and extending of existing content in pursuit of further improvement	Bruns (2008)
Connected learning	Learning occurs across and through media and contexts by young people, often in informal and innovative ways.	Ito et al. (2010)
Mobile literacy	It is the ability to use social media and media for learning through the mobile web.	Parry (2011)
Connected learning	Learning occurs with and through networked information and resources.	Tiemens (2008)

Source: Authors' own work.

students to actively explore, collaborate and construct knowledge in innovative ways, thereby taking a more active role in their learning process. Additionally, successful PBL requires situations where problems are authentic, unstructured and complex. Also, scaffolding is necessary to assist students in making their thinking visible, managing their inquiries, and evaluating and reflecting on their learning. However, the literature also recognises that students often need help with PBL, leading to adaptation challenges or resistance to the approach, possibly because of a lack of SDL skills. To achieve the best possible outcomes in PBL, more research is needed to investigate students' epistemic beliefs and their influence on their ability to self-direct their learning, which has been under-investigated in past research.

Inquiry-based learning as an engaging pedagogy

It is interesting that unlike:

> *[T]*raditional classroom learning, where a teacher presents facts and knowledge about a subject, inquiry-based learning is an educational strategy in which students follow methods and practices like those of professional scientists to construct knowledge. (Bauld 2023, n.p.)

The spirit of inquiry has a robust historical antecedent in Ancient Greece, as does the questioning method employed by Socrates when engaging in dialogue with his interlocutors (Alberta Education 2010). Students collaborated to create new knowledge while learning to 'think critically and creatively, and how to make discoveries through inquiry, reflection, exploration, experimentation, and trial and error' (Alberta Education 2010, p. 19).

The inquiry-based approach asks questions, seeks information and finds new ideas related to an event (Duran & Dökme 2016). It is an inherently human process of collecting information through the senses, a process that commences with birth and continues throughout one's life. Inquiry-based learning is more than merely asking questions; it is a complex process where information and data are converted into practical knowledge.

The inquiry-based approach encourages students to ask questions and investigate real-world problems. The students actively learn because they can explore, formulate and pose questions about real-life experiences. It is a process of discovering new causal relations, with the student developing hypotheses and testing them by conducting experiments and making observations (Pedaste et al. 2012). In this teaching and learning environment, opportunities are created for students to actively engage in the learning process; they explore and investigate real-life experiences. This means they can align what they experience and learn in the classroom with real-world situations outside the classroom. This approach stimulates critical thinking, and the students acquire critical thinking and problem-solving skills and develop creativity. Inquiry-based learning also emphasises active participation and the student's responsibility for discovering knowledge from any new STEAME component (De Jong & Van Joolingen 1998). Hence:

> Inquiry-based learning aspires to engage students in an authentic scientific discovery process. From a pedagogical perspective, the complex scientific process is divided into smaller, logically connected units that guide students and draw attention to [essential] features of scientific thinking. (Pedaste et al. 2015, pp. 47–61)

Therefore, moving to an inquiry-based approach within the STEAME framework is essential. Students are encouraged to engage in IBL elements such as asking questions, inquiring, problem-solving and decision-making processes. In the inquiry-based framework, the student investigates scientifically oriented questions, prioritises 'evidence in responding to questions, formulates explanations from evidence, connects explanations to scientific knowledge, and communicates and justifies explanations' (Banerjee & Chaudhury 2010).

Contemporary science reform movements emphasise that inquiries in science teaching are necessary and that science should be taught to students using the inquiry-based approach. An inquiry-based approach can ensure that students acquire the knowledge and develop the ability and skills to direct their learning by taking responsibility and initiative to collect enough resources and evaluate their learning strategies and outcomes, beginning SDL.

Inquiry is an exciting way to teach and learn. Teachers, therefore, should have the pedagogical orientation and skills to guide students towards exploring and experimenting with the various subjects of STEAME to find new ideas and obtain scientific knowledge effectively by utilising the inquiry-based approach. By incorporating IBL, intentionality and peer collaboration in their lesson plans, they provide opportunities for active participation, critical thinking and social interaction, aligning with the principles of constructivism and humanism in education (Van der Walt & Evans 2019).

Alberta Education (2010, pp. 5–6) advocated for education to be transformed around three fundamental principles.

> *Engaged thinker*: These are students who (a) think critically and make discoveries; (b) effectively use technology to learn, innovate, communicate, and discover; (c) work with multiple perspectives and disciplines to identify problems and find the best solutions; (d) communicate these ideas to others; (e) adapt to change with an attitude of optimism and hope for the future.
>
> *Ethical citizen*: These are students who (a) build relationships based on humility, fairness, and open-mindedness; (b) demonstrate respect, empathy, and compassion; and (c), through teamwork, collaboration, and communication, contribute fully to the community and the world.
>
> *Entrepreneurial spirit*: These are students who (a) create opportunities and achieve goals through hard work, perseverance, and discipline; (b) strive for excellence and earn success; (c) explore ideas and challenge the status quo; (d) is competitive, adaptable, and resilient; and (e) has the confidence to take risks and make bold decisions in the face of adversity.
>
> (Alberta Education 2010, pp. 5–6).

Problem-based learning fosters critical thinking by presenting real-world issues or challenges for students to explore, encouraging active engagement and IBL (Ge & Chua 2019). It enhances problem-solving skills by immersing students in situations requiring analysis, collaboration and creative solutions, preparing them to address complex issues they might encounter in their future careers or daily lives.

Engaging pedagogies and multiple intelligences

In this section, we will delve into the core concepts of MI theory, its criticisms and its compatibility with SDL. Additionally, we will explore how MI theory aligns with STEAME education, creating a rich tapestry of educational opportunities that cater to individual strengths and preferences. Howard Gardner's MI theory has profoundly impacted education. Gardner posits that intelligence is not a monolithic entity measured by a single IQ score but rather a multifaceted construct consisting of seven distinct and independent modalities, later adding an eighth one (Gardner 2020). Each individual possesses varying degrees of this intelligence, resulting in a unique combination of strengths and abilities that allow them to excel in different domains.

Gardner originally proposed seven distinct intelligences: verbal/linguistic, musical, logical-mathematical, visual/spatial, bodily-kinesthetic, intrapersonal and interpersonal. Sulaiman, Abdurahman and Rahim (2010) added an eighth intelligence, naturalistic intelligence. Additionally, Gardner introduced existential intelligence, focusing on 'fundamental questions about existence, life, and death' (Roberts 2010, p. 242). This tentative addition likely explains why Gardner (2012) refers to his model as comprising 8½ intelligences. He identified eight well-established types of intelligence and one additional type that remains tentative or not fully established. The '½' indicates that the ninth type of intelligence is still under consideration and not definitively included in his list.

Scholars and teachers have raised several critical points of contention with MI theories. However, it is important to remember the potential impact of Gardner's theory on education. Firstly, the theory lacks robust empirical evidence to substantiate its claims, with limited scientific research available to validate the existence and independence of the proposed intelligence. Secondly, the various intelligences identified by Gardner often overlap significantly, blurring the lines between them and making it challenging to distinguish them as separate forms of intelligence. This potential impact underscores the significance and relevance of the work of teachers in this field.

Another criticism pertains to the theory's potential cultural bias, which may favour Western values and education systems, potentially limiting its applicability in culturally diverse contexts. Furthermore, MI theory has been criticised for its limited practical applications in educational settings. It lacks specific guidance and a clear framework for teachers to implement it effectively in the classroom, leading to ambiguity and inconsistency in its application.

Addressing self-esteem and individual potential

In addition to the criticisms, there is concern that MI theory, like traditional IQ theory, could inadvertently limit students' self-perception and pigeonhole them into specific intelligence categories. Some argue that there are better ways to boost self-esteem based on factual assessments rather than the illusion of categorisation. It is essential to encourage students to recognise the value of their practical, physical and creative abilities alongside more abstract subjects. Such encouragement can be achieved without necessarily relying on MI theory. The idea that individuals possess predetermined innate abilities in specific MI areas can be as limiting to self-perception as traditional IQ theory, albeit in a more pluralistic form.

The holistic view of multiple intelligence theory

Despite its criticisms, the theory offers a broader perspective on intelligence and the potential to inspire alternative educational and individual development approaches. A modern approach highlights individual students' strengths, encouraging them to expand their thinking skills (Gardner 2020). Gardner himself emphasised that MI should be viewed as a supportive tool to aid in achieving educational goals. He argues that MI cannot be explored outside the cultural boundaries where each individual possesses unique strengths and weaknesses across these intelligences, necessitating different pedagogical styles to support their learning.

Gardner (2020) asserts that as each human has [their] unique intelligence configuration, we should consider that when teaching, mentoring or nurturing. We should teach individuals in a way that favours how they learn. Equally so, we should assess students in a way that allows them to show what and how they understood and apply their knowledge and skills in unfamiliar contexts.

The current one-size-fits-all educational approach predominantly focuses on standardised testing, potentially stifling students' authentic learning potential. If Gardner's assertions about MIs hold, and state assessments remain limited to measuring linguistic and logical-mathematical intelligence, there is a pressing need for a comprehensive overhaul of the education system to ensure more accurate assessments of students' actual knowledge.

Cultural considerations in intelligence

One aspect of Gardner's theory that holds significant relevance, particularly for universities in developing countries, is his recognition of the influence of cultural values on intelligent behaviour. Gardner highlighted that intelligence cannot be divorced from cultural contexts; hence, the presentation of intelligence is shaped by cultural values. This insight underscores the importance of acknowledging cultural diversity and context in assessing and nurturing intelligence.

The challenge of practical application

Acknowledging that MI theory faces challenges in practical application is crucial. Firstly, the theory needs predictive solid power, making it easier to implement effectively in everyday educational contexts. Secondly, the identification and categorisation of intelligence can be subjective, with no standardised measurement or assessment tool available to determine their presence or strength. This subjectivity raises concerns about the reliability and consistency of applying the theory in practice (White 2005).

Multiple intelligence theory and self-directed learning

A pivotal question emerges: How can MI theory be integrated with SDL? Self-directed learning empowers individuals to take initiative and responsibility for their learning journey. It involves setting personal learning goals, identifying relevant resources and independently managing one's learning process. Self-directed students actively seek information, engage in problem-solving and reflect on their learning experiences. The synergy between MI theory and SDL lies in their capacity to complement each other in various ways.

1. *Identifying strengths*: Multiple intelligence theory helps self-directed students recognise their strengths and intelligences. Understanding one's dominant intelligences allows students to tailor their learning strategies to capitalise on their strengths and engage with the material in ways that align with their preferred modes of intelligence.
2. *Exploring diverse learning opportunities*: Both theories encourage self-directed students to explore various learning opportunities. Self-directed students seek resources and experiences that cater to different intelligences, fostering a more holistic and personalised approach to learning.
3. *Choosing learning paths and strategies*: Multiple intelligence theory informs self-directed students' choices of learning paths and strategies. By considering different intelligences, students can select approaches that align with their preferences and strengths, enhancing motivation and engagement in the learning process.
4. *Respecting diverse learning styles*: Both theories emphasise respecting diverse learning styles and intelligences. This recognition fosters inclusivity in education and acknowledges that individuals possess unique combinations of intelligence.

Examples of how STEAME education can be aligned with the MI theory include designing activities that cater to different types of inteligences. The main aim should be that STEAME education provides a more inclusive and personalised learning experience by recognising and integrating various intelligences. Students should be allowed to leverage their strengths, fostering a holistic approach to education that aligns with the principles of the MI theory.

Problem-solving, design thinking and mathematical reasoning will support individuals with spatial and logical-mathematical intelligence strengths. Hands-on activities, prototyping and physical engagement can appeal to individuals with bodily-kinaesthetic intelligence. Integrating arts and communication allows for expressing ideas through music, language and other creative forms, catering to individuals with musical and linguistic intelligence. The entrepreneurial aspect of STEAME encourages creative problem-solving, innovation and a proactive approach, aligning with Gardner's notion of diverse intelligence contributing to effective functioning in the real world. Integrating MI theory and SDL offers a promising avenue for creating dynamic, inclusive and personalised learning environments. Multiple intelligence theory expands our understanding of intelligence beyond traditional academic measures and encourages teachers and students alike to embrace diversity in cognitive abilities. When combined with SDL, this approach empowers individuals to take control of their education, recognise their strengths and engage with learning in ways that resonate with their unique intelligence.

Furthermore, the alignment of theory with STEAME education presents a holistic educational approach that leverages interdisciplinary learning, creativity and personalised instruction. By integrating these multifaceted approaches, teachers can create vibrant, inclusive and engaging learning environments that cater to their students' diverse talents and passions.

As we navigate the evolving landscape of education, we must continue to explore innovative approaches that honour individuality, embrace cultural diversity and inspire lifelong learning. Multiple intelligence theory, emphasising diverse intelligence, offers a valuable framework for achieving these goals, whether in the classroom or on an SDL journey.

As a side note, the distinction between MIs and learning styles lies in their attributes, development flexibility and educational implications. While MI theory suggests a diverse range of cognitive abilities, learning styles focus on individual preferences for processing information. Teachers may find value in acknowledging both perspectives to create inclusive and effective learning environments. This is the link that should be established between process and person.

Embodied, situated and distributed cognition

The ESDC perspective emphasises the importance of affective development in learning (Clark 1998). An often-overlooked reason for poor performance in science is neglecting the affective domain of human thinking in science education. Neglecting the affective domain in science education may account for underperformance in STEAM education. The affective domain comprises multifaceted aspects encompassing student motivation, attitudes, perceptions and values. Lecturers can significantly enhance their pedagogical effectiveness by conscientiously integrating the affective domain into the structuring of courses, teaching resources and activities, and evaluation of student learning. Given its association with student attitudes and beliefs, a fundamental aim for teachers should revolve around fostering in students the conviction that STEAME holds practical significance and aligns with their educational aspirations.

The affective domain accentuates personal development, self-regulation and cultivating concentration abilities. In addition to cognitive achievements, teachers commonly prioritise the development of positive attitudes as a critical outcome within the affective realm. The affective domain's profound impact on learning manifests through observable behaviours that signify curiosity, attentiveness, concern and accountability (Lomas, Grootenboer & Attard 2012). The affective domain of learning can be enhanced by consciously rating students' pre-existing knowledge, backgrounds and environments. This approach can amplify the potential to foster emotionally significant experiences, facilitating their integration into long-term memory (ed. Hardy-Vallée 2009).

Embodied cognition denotes the brain's interconnectedness with the body, while situated cognition entails the synergy between the brain and body within our surroundings (Clark 1998). These structural elements extend beyond mere tools, constituting integral components intertwined with our cognitive processes. Andy Clark refers to these environment-related regularities supporting cognition as external scaffoldings (Clark 1998). Our daily growth, learning and actions rely on these scaffoldings, with language paramount. Human language, cultures and institutions facilitate expansive thinking beyond the confines of the brain, body or immediate setting. Cognition is thus embodied, situated within an environment and distributed across external structures. Networks of situated brains collaboratively process information.

Persistent sensorimotor dynamics, action's role in perception and learning, the interaction between agents and their environment, and collective intelligence are critical cognitive determinants essential for effectively defining natural cognitive systems and constructing artificial ones to accommodate new learning and knowledge creation. Learning occurs markedly more efficiently if this conceptualisation of the mind is synced with the affective domain. Cognitive processes encompass sensorimotor processes (motricity, perception, emotions, coordination, imagery, emulation and simulation) and substrates (members, bodies, artefacts and environmental regularities). These models stress cognition's embedded nature within the body and the world. Despite conceptually distinguishing the brain, body and environment, a continuous stream of dense information interlinks the three.

Integrating IK into the curriculum and engaging pedagogies for SDL holds promise for rendering science more engaging and relevant. Such an approach may enhance performance, particularly when teachers consider students' background, existing knowledge and context while scaffolding learning through activities.

The ESDC perspective posits that learning cannot occur in a vacuum. Effective learning thrives in environments that recognise students' existing knowledge, backgrounds and surroundings. Experiences infused with emotion are more likely to be etched into long-term memory. Students might steer their learning trajectory through engaging pedagogies and attain expertise in their respective fields. This pedagogical approach prioritises students' existing knowledge, backgrounds and environments.

Conclusion

In response to contemporary challenges, education must adapt by utilising problems to enrich learning and nurture creativity. Students should be equipped with the skills to address and navigate the complexities of ill-structured problems effectively. These problem-solving techniques should be designed to accommodate the diverse range of students, enabling them to engage and leverage their MIs effectively. Integrating collaborative learning can potentially metamorphose problems into catalysts for innovation, thereby igniting creative thinking in students. The chapter delves into engaging pedagogies such as problem-based and CL, offering student-centred teaching approaches. We emphasised the significance of empowering students to take ownership of their learning process and to prioritise art in the form of creativity, innovation and entrepreneurial mindset within STEAME education. Students are now engaging with a 'niche digital landscape outside of school' (Scott 2015, p. 14), and the roles of lecturers and other professionals should ideally be harmonised with this reality inside of school.

Chapter 8

Bridging the gap: The interplay of critical thinking, problem-based learning and mathematical modelling

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'Mathematics reveals its secrets only to those who approach it with pure love, for its own beauty.' – Archimedes

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Abstract

In the realm of university-level mathematics education, the integration of critical thinking (CT), problem-based learning (PBL) and mathematical modelling (MM) plays a pivotal role. These concepts are essential for nurturing students' cognitive abilities, refining their problem-solving skills and preparing them to navigate the complexities of an ever-evolving world. Critical thinking empowers students to critically evaluate environmental, social and economic issues, while PBL fosters an understanding of the interdependence between diverse global challenges. Critical disposition, reflecting one's mindset and attitude, complements critical abilities, which encompass the specific skills and cognitive processes necessary for critical thought. In this chapter, we delve into the definitions and significance of each concept (CT, PBL and MM); explore their historical aspects; analyse dispositions and abilities associated with CT, PBL and MM; and examine their relationships with other types of thinking. We also explore creative and innovative approaches to fostering CT, PBL and MM dispositions and abilities. Finally, we provide critical reflections on the transferability of modelling, CT, and PBL skills, abilities, dispositions and approaches.

Introduction

Mathematics, often perceived as the universal language, has been fundamental to human progression. Tracing back to ancient civilisation and its contemporary influence on scientific and engineering advancements, the significance of mathematics is profound. Mathematics transcends numbers and equations, venturing into cognitive prowess honed by critical thinking (CT) and problem-solving skills (Belecina & Ocampo 2018). This chapter explores the interplay of CT, problem-based learning (PBL) and mathematical modelling (MM), elucidating how their synergy fosters adept and holistic learners.

A holistic teaching and learning approach to mathematical education advocates for the nurturing of CT and problem-solving skills, positioning them as the cornerstones of a successful mathematical journey. Numerous scholarly contributions have underlined this connection, establishing that the development of a critical mindset is intrinsically tied to successful mathematical problem-solving (Chukwuyenum 2013; Jacob 2012; Semerci 2005; Kriel 2013; Buitrago-Flórez, Danies, Restrepo & Hernández 2021). Current academic discourse showcases a resonating theme – a positive association between CT and commendable academic outcomes in mathematics (Arisoy & Aybek 2021; Awofala & Lawal 2022; Thorndahl & Stentoft 2020). The global pedagogical emphasis on fostering CT in mathematics is reflected in curricula worldwide, including the vibrant landscapes of South African mathematical education.

In this narrative, a debate occasionally arises concerning the juxtaposition of critical and creative thinking. Some in the academic sphere may advocate prioritising one over the other, but it is a juxtaposition that can be considered superficial at best (Astuti 2021). What truly shapes a holistic thinker is the harmonious blend of critical evaluation and creative ideation, equipping individuals to navigate complex challenges in diverse arenas while pushing the boundaries of innovation, all while remaining anchored in practicality.

Critical thinking represents a cognitive process that encompasses the analysis, evaluation and synthesis of information to make reasoned judgements and informed decisions (World Economic Forum [WEF] Annual Meeting 2023). In the context of mathematics education, CT empowers students to assess the validity of mathematical arguments (Paul & Elder 2019), identify logical fallacies (Suter 2012) and develop rigorous proofs (Elder & Paul 2020; Paul & Elder 2019). It serves as a fundamental skill enabling students to approach mathematical problems thoughtfully and independently, fostering a deep understanding of mathematical principles and their practical applications (Brown 2016).

Problem-based learning, on the other hand, is an educational approach centred around students actively engaging in solving real-world problems (Bell 2010). Within the realm of mathematics, PBL challenges students to apply mathematical concepts to practical scenarios, thereby fostering a deeper understanding of mathematical principles and their relevance in everyday life. This approach promotes collaborative learning (Koschmann et al. 2012; Pluta, Richards & Mutnick 2013; Zhang, Peng & Hung 2009; Paul et al. 1990) and effective communication (Azer 2001; Deep, Salleh & Othman 2019) and prepares students for the challenges of a diverse and interconnected world (Semerci 2005).

Moving to MM, it involves representing real-world scenarios or systems using mathematical equations and concepts (Govender 2020; Jacob 2012). Through this process, students gain the ability to analyse complex phenomena, make accurate predictions and gain deeper insights into real-world problems. Engaging in MM exercises cultivates students' analytical and quantitative skills, empowering them to approach real-world challenges with confidence and precision (Govender 2020).

Moreover, it is important to note that CT is intimately connected with other types of thinking, including creative thinking and problem-solving (Chikiwa & Schäfer 2018; Semerci 2005; Suter 2012). Creative thinking involves the generation of novel ideas and innovative solutions, while problem-solving focuses on finding resolutions to specific issues. Critical thinking complements these processes by evaluating and refining creative ideas and ensuring the soundness of problem-solving approaches (Chukwuyenum 2013). It equips students to scrutinise and analyse their creative solutions, determining their effectiveness and practicality in real-world contexts.

Within the realm of CT, critical disposition and critical abilities are fundamental concepts (Aizikovitsh-Udi & Cheng 2015; Ennis 1987; Silver and Kenney 1995). They both play vital roles in developing an individual's capacity for independent and analytical thought, yet they refer to different aspects of the CT process. Critical disposition refers to an individual's attitude or inclination towards thinking critically, involving an open-minded, curious and reflective approach to information and ideas (Aizikovitsh-Udi & Cheng 2015; Ennis 1987; Rudd, Baker & Hoover 2000). A person with a critical disposition is willing to question assumptions, challenge established beliefs and engage in rigorous examination of evidence before forming opinions or making decisions. It involves intellectual humility, a willingness to entertain diverse perspectives and a commitment to seeking truth and understanding. On the other hand, critical abilities refer to the specific skills and cognitive processes that enable individuals to think critically and make sound judgements, encompassing aspects such as analysing information, evaluating arguments, identifying biases and synthesising diverse sources of information to draw well-founded conclusions. These abilities involve the application of logic, evidence and reason to assess the validity and reliability of information and arguments (Rudd et al. 2000).

Furthermore, critical disposition forms the underlying mindset that drives the use of critical abilities (Aizikovitsh-Udi & Cheng 2015). It sets the tone for how a person approaches information and problems, encouraging them to be curious, inquisitive, willing to suspend judgement, trust in reason, seek the truth and be receptive to new ideas. Without a critical disposition, even individuals with strong critical abilities may hesitate to challenge their own beliefs or explore alternative viewpoints. While critical disposition pertains to one's mindset and approach to thinking, critical abilities are the cognitive tools and techniques employed to carry out CT (Ennis 1987). Possessing critical abilities allows an individual to implement their critical disposition effectively, enabling them to approach problems and decision-making with a systematic and rational approach. These critical abilities encompass observation, emotional, questioning, imaginative, inferential and experimenting abilities.

Mathematics has always been a cornerstone of human development, from ancient civilisations to modern science and engineering. At its core, the beauty of mathematics lies not only in numbers and formulas but also in the CT and problem-solving abilities it fosters. This chapter delves into the intricate relationships between CT, PBL and MM, illustrating how the confluence of these three pillars is essential in nurturing competent and holistic learners.

Historical glimpses

Historically, each of these educational concepts has rich roots and significant contributions that have shaped its evolution. Mathematical modelling, for instance, has its origins in ancient civilisations such as the Babylonians and Egyptians. During these times, mathematical methodologies were employed to tackle practical issues in agriculture, architecture and commerce. Pioneers such as Archimedes, Leonardo Fibonacci and Isaac Newton further enriched the domain of MM, making it integral in contemporary science and engineering.

During the Renaissance, thinkers such as René Descartes and Galileo Galilei brought CT to the forefront of mathematical education, emphasising meticulous reasoning in mathematics and science. Their legacy inspires learners to approach mathematical tasks with intellect and precision. In the 20th century, PBL gained traction, influenced by reformists like John Dewey (2022), emphasising experiential and student-centric learning. Additionally, Howard Barrows' innovative propositions at McMaster University School of Medicine in Canada in 1969 gave PBL a firm footing in modern education (Anderson & Lawton 2007; Savery 2015; Saven-Baden & Major 2004). As described in several studies, PBL, in its essence, revolves around addressing authentic problems using scientific methodologies (Orozco & Yangco 2016). This approach has subsequently cemented its place in mathematics education, nudging students towards active problem-solving, thus stimulating creativity and autonomy.

The synergy of CT, PBL and MM, is crucial in shaping proficient mathematicians, especially at the tertiary level. By imbibing these principles, learners are equipped with the arsenal to confront real-world quandaries and play pivotal roles in societal progress. By intertwining critical and creative thought processes, educators can sculpt students who are adept at unravelling intricate issues, laying the groundwork for transformative impacts across diverse sectors. As a result, a meticulously designed curriculum, infused with these principles, primes students to be agile, assiduous and ready for the dynamism of the modern era.

The intrinsic unity of critical thinking, problem-based learning and mathematical modelling

Higher education's evolving landscape demands dynamic adaptations aligned with a transforming world. The focus has shifted from merely acquiring knowledge to ensuring students can adeptly apply it in real-world contexts. This evolution highlights the amalgamation of MM, CT and PBL as a powerful academic trio crucial for moulding perceptive problem-solvers and incisive thinkers (Elder & Paul 2020). Mathematical modelling emerges as the foundational framework, presenting a methodical avenue to tackle real-life challenges. However, the infusion of CT breathes life into this framework. It drives students to venture beyond mere computational tasks, prompting them to delve into deeper analytical terrains marked by questions of 'why' and 'how'. Such profound analysis ensures that students do not merely address problems but also grasp their inherent nuances. Contrarily, PBL breaks away from conventional teaching paradigms. It plunges students into genuine dilemmas, often without clear-cut solutions, pushing them to bridge theoretical insights with tangible applications (Kloppers & Grosser 2014). Within this enriched learning environment, students exercise not only their mathematical prowess but also hone essential skills such as teamwork, adaptability and communication. Such an approach guarantees a rounded education, aligning academic pursuits with their real-world implications.

Nevertheless, the essence of MM is not confined to the mere translation of worldly issues into mathematical syntax (Jacob 2012). It gives students an analytical prism, simplifying convoluted situations and underscoring the omnipresence of mathematics in diverse facets of life, from the intricacies of economic fluxes to nature's marvels. In the domain of MM, learners confront the task of converting complex worldly dilemmas into mathematical expressions, followed by their resolution. Amid these challenges, the tenets of self-directed learning (SDL) become paramount. Self-directed learning empowers learners to spearhead their learning trajectory, from identifying needs and sourcing resources to evaluating their progress (Kim & Kim 2010). Such an independent foray into MM inadvertently nurtures CT. Faced with convoluted scenarios, learners are nudged to scrutinise information, evaluate its veracity and weave it cohesively. They must judiciously select mathematical techniques, validate their models and contextually interpret outcomes.

Problem-based learning has great potential for enhancing SDL by fostering autonomy, CT and problem-solving skills. This dynamic connection between CT, PBL and SDL is a powerful catalyst for lifelong learning. In PBL, students take charge of their learning, identifying real-world problems and setting their own goals. This sense of ownership is a cornerstone of SDL, where individuals actively direct their learning. Problem-based learning further stimulates SDL by promoting active engagement, as students seek knowledge to solve real challenges driven by their curiosity. Critical thinking, integral to PBL and SDL, plays a pivotal role (Awofala & Lawal 2022). Problem-based learning requires critical analysis of problems and solutions, supporting SDL's self-assessment and adaptability.

Additionally, the complexity of these challenges deems them suitable for the PBL method. Problem-based learning, rooted in problem-solving, resonates with the intricacies presented by MM. An active quest for solutions allows learners to optimise their learning strategies, rendering PBL and SDL as harmonious educational pillars. Mathematical modelling thus serves as a channel, integrating the principles of SDL (Sukardjo & Salam 2020). This synergy enhances CT and capitalises on the virtues of PBL, arming learners with a comprehensive arsenal to navigate mathematical complexities (Choi, Lindquist & Song 2014).

The enchantment truly materialises when MM, CT and PBL coalesce seamlessly. It is about crafting a symbiotic relationship among them to elevate each component's efficacy. Envision a student simulating an epidemic's spread, dissecting their model's intricacies and collaboratively ideating preventive tactics in a PBL setup (Bae et al. 2005). This approach not only aligns with modern academic requisites but also heralds a future-ready mindset, equipping students for a world characterised by rapid technological metamorphosis and layered global dilemmas (Innabi & Sheikh 2007).

In conclusion, the triad of CT, PBL and MM goes beyond being a progressive educational strategy; it can be regarded as prophetic. As we traverse an epoch marked by unprecedented innovation and challenges, there's a pressing need for learners equipped to evaluate, adapt and incessantly innovate. This integrated pedagogical paradigm, anchored in the three tenets, sketches a roadmap to this ideal. It readies contemporary learners to excel today while influencing tomorrow. By comprehending the intricate synergy among these educational keystones, we can forge a learning milieu that is academically robust and profoundly pertinent, preparing students for the multifaceted challenges of our intricate world.

Relationships of critical thinking to other forms of cognitive engagement

In the realm of cognitive processes, CT stands out as a cornerstone. However, its true depth and breadth are best appreciated when viewed in harmony with other forms of cognitive engagement. To grasp its full significance, we must delve into its intricate relationships with creative thinking, problem-solving and higher-order thinking, each relationship illuminated by real-life examples.

Critical thinking and creative thinking, though often perceived as opposites, are in fact deeply complementary. While CT offers an analytical lens through which we assess and evaluate, creative thinking is the spark that ignites innovation and imagination. For instance, in the realm of urban planning, the envisioning of sustainable infrastructure might involve brainstorming innovative concepts such as vertical gardens or renewable energy solutions, a testament to creative thinking. However, the subsequent phase, where these ideas are assessed for feasibility, cost-effectiveness and potential impact, is where CT comes into play, as highlighted by Minott, Ferguson and Minott (2019).

Problem-solving serves as a nexus, bridging the gap between critical and creative thinking. It demands both the generation of innovative solutions and the rigorous evaluation of their viability. Take the medical field as an example: when researchers are confronted with a novel virus strain, their initial approach involves brainstorming potential treatments or vaccines, a process rooted in creative thinking. Once a range of possibilities emerges, CT takes the reins, evaluating each potential solution based on criteria such as efficacy, side effects and scalability.

Higher-order thinking, meanwhile, represents the pinnacle of cognitive engagement. It encompasses a range of complex cognitive tasks, from analysis to synthesis, all deeply rooted in the principles of CT. In the context of literary studies, students go beyond merely recalling facts about a story, a task that represents lower-order thinking. Instead, they might delve into evaluating a character's decisions, interpreting underlying themes and drawing parallels between the literary work and contemporary societal issues, as noted by Suter (2012). Such deep, multifaceted engagement with the material is a testament to the power of higher-order thinking, underpinned by critical analysis and interpretation.

In wrapping up, while each cognitive process – be it CT, creative thinking, problem-solving or higher-order thinking – has its unique attributes and strengths, it is their synergistic interplay that truly elevates human cognition. As highlighted by scholars such as Scriven and Paul (1987) and Semerci (2005), recognising and nurturing the interconnectedness of these processes can unlock unparalleled cognitive capabilities, fostering innovative solutions, profound insights and a richer understanding of our multifaceted world.

Problem-based learning has the potential to yield significant affective outcomes that, in turn, influence the cognitive domain of learning. For example, when students engage in PBL activities, they often encounter complex, real-world problems that require not only cognitive skills but also emotional and motivational involvement (Astuti 2021). This emotional engagement can foster a sense of curiosity, intrinsic motivation and a growth mindset, all of which are affective aspects of learning. As students grapple with challenges and collaborate with peers, they may experience emotions such as curiosity, frustration and satisfaction. These emotional experiences can impact their cognitive processes, influencing their ability to critically analyse problems, persist in finding solutions and develop a deeper understanding of the subject matter. Essentially, the affective domain feeds into the cognitive domain by shaping students' attitudes, motivation and emotional responses, ultimately enhancing their cognitive engagement and learning outcomes in PBL scenarios.

Syntax in developing critical thinking, problem-based learning and mathematical modelling

There's a structured approach (or syntax) to integrating CT, PBL and MM into the educational curriculum. Just as there's a method to solving mathematical problems, there's a structured approach to teaching and learning these skills. For instance, introducing students first to basic models, then challenging them to think critically about their limitations and, finally, placing them in a problem-based scenario where they can apply their understanding (Arisoy & Aybek 2021; Astuti 2021; Jacob 2012). This step-by-step, structured approach enhances comprehension and retention.

Critical thinking, PBL and MM cultivate various dispositions in learners, such as habits of inquiry, attentiveness and open-mindedness (Kriel 2013). Engaging with mathematical models, for instance, fosters habits of inquiry and attentiveness. Critical thinking promotes open-mindedness, willingness to suspend judgement and trust in reason (Lamont 2020). Problem-based learning encourages cooperative learning, resilience in the face of challenges and adaptability. Together, they shape not just what students know but also how they approach learning and problem-solving. For example, the work of Johnson and Johnson (1986, 1998) discussed the potential for both cooperative learning and PBL to provide opportunities for students to develop essential SDL skills, such as self-assessment, CT, collaboration and autonomy (Leary et al. 2019). These approaches create environments where students are actively engaged in their learning and encouraged to take ownership of their educational journey.

The essence of these concepts lies in its structure and methodology. Drawing parallels with the systematic nature of solving mathematical problems, the integration of CT, PBL and MM into the curriculum can be envisioned as a multi-stage journey.

1. **Foundational introduction: Building the base**

- *Objective*: Lay the groundwork for students, ensuring they have a solid understanding of the basic principles.
- *Method*: Use interactive sessions, workshops and hands-on activities to introduce students to elementary models.
- *Outcome*: Students gain a clear understanding of the foundational concepts, setting the stage for deeper exploration.

2. **Critical evaluation: Sharpening the analytical lens**

- *Objective*: Develop students' ability to critically assess, challenge and refine their understanding.
- *Method*: Organise debates, group discussions and case studies where students can dissect models, identify their limitations and question underlying assumptions.
- *Outcome*: Students cultivate a critical mindset, enabling them to discern nuances and understand the intricacies of models and theories.

3. **Real-world application through PBL: Bridging theory and practice**

- *Objective*: Equip students with the skills to apply their knowledge in real-world contexts.
- *Method*: Design problem-based scenarios, simulations and projects that mirror real-world challenges, allowing students to implement their understanding.
- *Outcome*: Students not only grasp theoretical concepts but also learn to apply them practically, enhancing their problem-solving abilities (Arisoy & Aybek 2021; Astuti 2021; Jacob 2012).

This structured, multi-tiered approach ensures a comprehensive understanding, fostering long-term retention and application of knowledge.

■ Beyond knowledge: Cultivating dispositions for developing cognitive skills

While skills and knowledge are fundamental components of education, the development of specific dispositions plays a pivotal role in shaping students' growth.

- **Mathematical modelling:**
  - *Impact*: Encourages a systematic and logical approach to problems.
  - *Benefits*: Students develop habits of meticulous inquiry, heightened attentiveness and a structured approach to problem-solving, reminiscent of mathematical analyses (Kriel 2013).

- **Critical thinking:**
  - *Impact*: Fosters a mindset of questioning, analysing and evaluating.
  - *Benefits*: Students embrace open-mindedness, patience and a deep-seated trust in logical reasoning, equipping them to dissect complex problems and scenarios.

- **Problem-based learning:**
  - *Impact*: Emphasises experiential learning and real-world application.
  - *Benefits*: It offers students numerous benefits, including active engagement, exposure to diverse perspectives, enhanced CT abilities and valuable real-world application of knowledge and skills. It can be an effective pedagogical approach for promoting meaningful learning experiences and preparing students for success in various contexts.

Together, this triad not only equips students with knowledge but also moulds their character, attitude and approach to learning. It ensures that they emerge as well-rounded individuals, ready to navigate the complexities of the modern world.

Critique of critical vs. creative thinking and bias in critical thinking and theory and pedagogy

In the realm of educational pedagogy, a longstanding debate persists: How do critical and creative thinking relate? While traditionally perceived as distinct or even antagonistic, their intertwined roles in the learning process paint a different picture. They are not merely interconnected; they are symbiotic. Imagine the birth of a groundbreaking idea. Creative thinking serves as the ignition, kindling a plethora of potential solutions and methods. It beckons a break from the usual, pushing limits and championing innovation. However, every idea, no matter how novel, requires scrutiny – a means to assess, hone and authenticate. Enter CT. It operates as the discerning lens, sifting through ideas, refining them and anchoring them in reason and practicality.

Take the seemingly straightforward task of determining a tree's height from the ground, as discussed by Govender (2020). The creative aspect lies in leveraging available mathematical models and crafting a strategy. Conversely, the critical aspect evaluates the strategy's viability, the potential margin of error and the underlying assumptions. Together, these thinking modes empower learners to not only conceive but also fine-tune, striking a harmony between novelty, practicality and mathematical precision. However, CT, despite its virtues, is not flawless. It aspires for objectivity and rationale but can fall prey to various biases. These biases might stem from cultural influences, personal histories or innate cognitive patterns.

Even evidence-backed pedagogical methods are not exempt. An educator might inadvertently favour certain theories, influenced by cultural biases. Textbooks might unintentionally marginalise specific groups or viewpoints, as noted by Kriel (2013). Even mathematical problems, often hailed as paragons of neutrality, can occasionally echo particular socio-cultural narratives, thereby excluding those unfamiliar with them (Makina 2010; Mason, Burton & Stacey 1982).

The ramifications of such biases run deep, moulding how learners perceive, assimilate and internalise knowledge. Thus, pinpointing these biases, grasping their roots and proactively mitigating them are pivotal for genuine pedagogy. It ensures that the process of CT remains unbiased and inclusive, letting learners interact with unadulterated information. While the synergy of critical and creative thinking enhances the educational experience, vigilance against biases ensures its authenticity and inclusivity. At its core, true education is not just about teaching thought but fostering holistic, innovative, unbiased and critical thought.

Thorndahl and Stentoft (2020) highlighted a prevalent belief: PBL promotes CT. However, a consensus on the 'why' remains elusive. This belief in the value of CT stands unchallenged, with current literature echoing its importance. Yet, Thorndahl and Stentoft (2020) also spotlighted a research trend: the overwhelming reliance on standardised tests to gauge CT. To truly fathom students' CT prowess, delving into their assignments and projects might be more revealing. Szenes, Tilakaratna and Mason (2015) argued that there is scant exploration of genuine 'critical thinking' manifestations in higher education or the academic practices deemed as evidence. The essence of students' written content and what educators value as CT indicators remain largely uncharted. If students cannot manifest CT in assignments, test scores become moot. Hence, the emphasis should be on nurturing students' practical application of CT. Ethnographic studies, focusing on students' independent assignments, could offer fresh, invaluable insights into their CT capabilities. True education goes beyond merely instructing learners to think; it emphasises holistic, unbiased thought processes. The interplay between critical and creative thinking elevates and enriches the entire learning journey.

Critical reflections on the transferability of critical thinking, problem-based learning and modelling

In the dynamic landscape of higher education, CT stands out as a fluid and evolving skill. Unlike static abilities, it demands consistent nurturing and refinement. When harmonised with the right mindset, it paves the way for learners to seamlessly integrate CT with other foundational skills (Rudd et al. 2000). For instance, effective communication often hinges on the critical dissection of information, while problem-solving necessitates analytical thinking, scenario interpretation and a systematic approach to solutions.

This intricate web of skills, with CT at its core, becomes indispensable when grappling with multifaceted challenges, spanning economic, social or environmental domains. As the world collectively steers towards sustainable development, these competencies become the torchbearers, enabling individuals to navigate intricate issues, pinpoint viable solutions and champion transformative change. Yet, a glaring disparity emerges when observing proficiency levels across learners. Alarmingly, many, even at higher echelons of education, appear to lack polished CT skills (Nauman 2017). This deficiency not only curtails individual potential but also poses a threat to collective advancement, particularly in the face of urgent sustainable development challenges.

Venturing into the realm of mathematics reveals a deep-seated symbiosis with CT. Mathematics transcends mere numbers and formulae; it embodies a language demanding meticulous thought, reasoning and analytical prowess. Echoing the sentiments of scholars like Cobb et al. (1992), true mathematical learning surpasses mere memorisation. It immerses learners in understanding, reasoning and practical application. This fusion of CT and mathematical pedagogy amplifies the richness of the learning experience, enabling students to not only calculate but also grasp concepts and reflect on mathematical nuances.

In the vast expanse of mathematical knowledge, its essence is truly realised when intertwined with CT and further enriched by PBL (Chukwuyenum 2013). This triumvirate forms a formidable educational foundation, setting learners on a trajectory towards unmatched academic and professional heights. In our rapidly shifting world, challenges both foreseen and unforeseen emerge persistently, necessitating agile problem-solving, incisive critical assessment and, often, the strategic deployment of mathematical frameworks. The comprehensive grooming offered by this educational synergy equips students to tackle such challenges head-on. Far from being mere academic tools, these skills morph into life competencies that are versatile, adaptable and globally relevant, fortifying students to confidently confront diverse real-world challenges.

To encapsulate, integrating CT, PBL and MM in education transcends mere curriculum enhancement. It signifies a transformative odyssey, reshaping the learning paradigm and arming students with a multifaceted skill set, aptly suited for the intricate fabric of real-world contexts. These competencies not only serve students in academic settings but also empower them to be trailblazers and agents of change in broader societal spheres.

Conclusion

The exploration of the interrelationships between CT, PBL and MM in this chapter underscores their integral role in reshaping modern mathematics education. As the world grapples with increasingly intricate challenges, the educational paradigms that once sufficed are being re-evaluated. The emphasis on fostering CT, PBL and MM has emerged not as a mere trend but as a genuine necessity.

The ability of CT to empower students to dissect and evaluate global issues, combined with the experiential learning approach of PBL and the practical applications offered by MM, forms a triad of educational strategies that prepare students for the real-world complexities they will inevitably face. Moreover, as highlighted by the World Economic Forum, these educational approaches align seamlessly with the pursuit of sustainable development goals, ensuring that students are not only knowledgeable but also equipped to contribute meaningfully to global solutions.

The fusion of CT, PBL and MM in mathematics education signifies a transformative approach that moulds students into critical thinkers, problem-solvers and innovators. Moving forward, educators, policy-makers and stakeholders must champion these strategies to prepare the next generation for future challenges.

Chapter 9

Inclusion in the STEAME classroom: Giving a voice to the marginalised

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Abstract

The concepts 'voice' and 'marginalisation' are integrally linked to educational inequality and neoliberal tendencies in public schooling in postcolonial contexts. Academic success in Science, Technology, Engineering, the Arts, Mathematics and Entrepreneurship (STEAME) at the primary school level provides a firm grounding for learners to meet the requirements for access to higher education later in their scholastic trajectory. It is evident that higher achievement in the early years boosts learners' self-confidence and offers the basic skills for mathematics and literacy that they need to achieve success in career fields associated with high economic and social status, thereby translating into better career prospects.

Since the advent of democracy in 1994, educational inequality in South Africa has not abated, in spite of the many policy documents that emerged from the democratic state. The current educational bifurcation into disadvantaged and well-resourced schools is a legacy of apartheid and the intersectionality of race and class. The neo-liberal and capitalist policies of the democratic dispensation have witnessed a continuation of socio-economic disadvantage and racial and class inequality. Racism in education is inextricably aligned to power relations and is reproduced in conjunction with various forms of marginalisation, particularly class and gender. As the history of oppression continues to disadvantage poor and vulnerable children within bifurcated school settings, we examine the critical question: How can the voices of children enhance their academic achievement and educational experience through participation in the STEAME classroom? The aim is to foreground children's voices as essential in the learning programme to counter the politics of marginalisation and inequality.

Introduction

Unearthing the lived experience of marginalised children in school settings in South Africa holds a central place in the work we do as teacher educators. Research on the 'Other' in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) in South Africa often focuses on women and is mainly aimed at access and participation in post-schooling. However, it is evident that higher achievement in the early years boosts learners' self-confidence and offers the basic skills for mathematics and literacy that they need to achieve success in career fields associated with high economic and social status, thereby translating into better career prospects. In fact, research shows that a good quality stimulation in basic schooling is essential, not only for task completion but also to be successful in the different phases of schooling and in post-schooling (Ramani & Siegler 2011). Feza (2018) argues that poverty indicators such as dependency on social welfare grants which impact the quality of adulthood can be reduced by accessing and participating in quality stimulation in STEAME.

With this in mind, we focus on quality stimulation in STEAME in basic education. We ask: How can the voices of children enhance their academic achievement and educational experience through participation in the STEAME classroom? We aim to foreground children's voices as essential in the learning programme to counter the politics of marginalisation and inequality in STEAME. Empowering children through 'voice' with meaningful access and participation in STEAME classrooms is about their ownership of space as active citizens and not necessarily as dependant subjects (Erickson & Faria 2011):

> A key component of empowerment is for citizens to develop self-esteem so those in positions of formal power do not need to evaluate or act upon them: by developing self-esteem, citizens enact power themselves, and the state does not have to do so. (Erickson & Faria 2011, p. 639)

To this extent, we interrogate inequality in basic education by looking at marginalisation in the broader spectrum of STEAME. We also address policy developments and teacher training within science, mathematics and technology. We use an intersectional lens to understand the importance of 'voice' in participation in STEAME for learners and to counter the politics of marginalisation and inequality.

We begin this chapter by mapping the South African context in relation to inequality, racial and class intersections and performances of learners on the margins. Thereafter, we discuss policy and practice in relation to STEAME subjects, as well as teacher support. We examine 'voice' as an instrumental concept in the inclusion and empowerment of poor, racialised learners living on the margins of South African schools.

Background and context of inequality in South African schools

The concepts 'voice' and 'marginalisation' are integrally linked to educational inequality and neoliberal tendencies in public schooling in postcolonial contexts. The educational situation in South Africa is exacerbated not only by the history of racial oppression and disadvantaged schooling for the majority of black children but also by the fact that children are the most vulnerable component of all societies and their voices are generally marginalised. Henry Giroux (2011) noted in his text, *On critical pedagogy*, that children have fewer rights than almost any other group and fewer institutions protecting these rights: 'Consequently, their voices and needs are almost completely absent from the debates, policies, and legislative practices that are constructed in terms of their needs' (p. 109).

Educational inequality in South Africa has not abated since the advent of democracy in 1994. Salim Vally (2023) maintains that:

> *[P]*resent-day educational segregation in post-apartheid South Africa must be examined with reference to the history of racial capitalism and to contemporary socio-economic and political disadvantage and patterns of inequality in society. Racism in education is inextricably [aligned] to power relations and [is] reproduced in conjunction with class, gender, and other inequalities. Education is embedded in social class relations and largely reflects and reinforces inequalities in a [racialised and] capitalist society. (pp. 189–190)

The notion of 'inequality in education' can be interpreted in various ways: inequality of access and opportunity given the dynamics of race, class and gender; and inequality of outcome within a 'township' schooling system for poor black African and coloured children which is mostly dysfunctional and under-resourced when compared to suburbs catering for middle-class children. Although Coloured people are considered black because of racial classification in South Africa, the term refers to people descended largely from Cape slaves, the indigenous Khoisan population and European settlers. Unfortunately, post-apartheid society is still stuck in racial frameworks, and Coloureds, continue to hold 'an intermediate status in the South African racial hierarchy, distinct from the historically dominant white minority and the numerically preponderant African population' (Zantsi 2020). While the state annually argues that the performance in the matriculation examination is increasing, there is much evidence that indicates major gaps in attainment between learners in a school system that is bifurcated.

Critical questions that educationalists should engage with, given the continuation of inequality in South Africa three decades after the advent of democracy, will include:

- What are the long-term disadvantages of learners who spend their lives on the margins of mainstream schooling?
- How does educational reform produce arrangements for schooling that contribute to marginalisation and increase inequality?

It is evident that neoliberal tendencies and market/capitalist policies that silence voices reinforce marginalisation. Stephen Ball (2010) uses the term 'economy of student worth' (p. 163) to refer to the tendency of marginalising poor children within the competitive class-based school system:

> The values and incentives of market policies being pursued and celebrated by the states give legitimation and impetus to certain actions and commitments – enterprise, competition, excellence – and inhibit and delegitimate others – social justice, equity, tolerance. The need to give consideration to the fate of others has been lessened in all this. (Ball 2010, p. 26)

■ Race and class intersections in South African schools

Middle-class parents can afford the higher fees of the well-resourced schools. The latter schools seek to achieve the best ranking with their pass rates and strive to maximise output performance and adopt internal procedures that prioritise one sub-group of learners over another in order to maximise their chances of a higher ranking. These schools prefer middle-class children who are more likely to be high-attaining, compliant students who are easy to teach. A child from a poor family is half as likely to attend a good secondary school as a non-poor child (Burgess & Briggs 2006, p. 23). Schools matter greatly in South Africa, and a significant proportion of the variance of learner attainment in national audits and, ironically, international tests like the TIMMS and the Progress in International Reading and Literacy Study (PIRLS) do not take into account disadvantaged schooling for children from low-income homes who rely on school meals, have educational needs, are limited to no parental involvement and have a history of lower attainment starting at Foundation Phase. Ironically, an analysis of the performance of South African learners in the PIRLS 2021 survey, with regard to the medium of instruction/language of learning and teaching (LoLT), highlights the intersection of race, class and poverty with academic achievement in basic schooling in South Africa. In PIRLS 2021, among South African Grade 4 learners, the vast majority (81%) could not read for meaning across all 11 official languages in South Africa. There was also an overall decline in their performance in comparison with the 2016 performance. However, a further analysis indicated no decline for English and Afrikaans learners, but a decline for learners attending schools where indigenous African languages are the LoLT (Department of Basic Education [DBE] 2023). Many of these schools are no-fee schools, meaning that they service the majority indigenous population, which is still primarily associated with poor socio-economic circumstances. Another major factor that leads to educational inequality is 'teacher effects', that is, teacher commitment, knowledge and attitude and how these feed into widening educational inequalities in disadvantaged schools. In addition, many schools situated in poor (therefore mostly African) communities have overcrowded classrooms. Overcrowded classrooms are associated with different negative factors influencing learning outcomes such as challenges with learner discipline, unsatisfactory teacher attitudes, lack of resources and didactical neglect (West & Meier 2020), making it difficult to provide support to learners with barriers and general decline in the quality teaching and learning (Venketsamy 2023).

Mathematics and science education in South Africa

The post-1994 democratic schooling system has witnessed many curricular changes (outcome-based education [OBE], Revised National Curriculum Statement [RNCS], Curriculum and Assessment Policy Statement [CAPS]) and a plethora of education policies aimed at improving mathematics and science education in South Africa. The policies serve two all-encompassing objectives – overcoming the almost five decades of apartheid heritage of severe racial injustice in access to quality education and developing critical human capital for the country's economic growth. The pre-1994 colonial and apartheid governments provided and institutionalised unequal access to education for different racial groups – separate education systems for white, coloured, Indian and African students. The key factor for the legacy of poor science achievement is the very unequal teaching resources provided for non-white children (Kallaway 2002); funding for white children was 2.5 times higher than that in Bantustan schools for African children (Case & Deaton 1999). The imbalance in the provision of educational resources has resulted in a bifurcation of affluent, functional schools and poor, dysfunctional schools (Van der Berg 2008, p. 5). The historical inequalities are exacerbated by poor school management largely because of the political role that organisations like the South African Democratic Teacher Union play in senior appointments at schools. Teacher unions 'are again compounded by current managerial inefficiencies which continue to affect the historically disadvantaged schools. Only about one third of schools could be considered as functional' (Van der Berg 2008, p. 5). Teacher training colleges preparing teachers for African schools often did not offer mathematics as a specialisation, and the consequence that still haunts the current schooling context is that African children were systematically underexposed to mathematics and science education (OECD 2008). Despite the post-1994 educational reforms, the most significant being the creation of a single DBE to promote equity in access to education, African learners still have severely underprivileged access to mathematics and physical sciences education. The DBE stressed the integral role of numerical, mathematical and analytical skills for children to participate as citizens in modern society and as workers in the new knowledge economy:

> Mathematics is a human activity that involves observing, representing and investigating patterns and quantitative relationships in physical and social phenomena and between mathematical objects themselves. It helps to develop mental processes that enhance logical and critical thinking, accuracy and problem-solving that will contribute in decision-making. (DBE 2011, p. 8)

Vijay Reddy from the Human Science Research Council maintains that the jobs which are in the highest demand and are best rewarded currently in

South Africa are those with mathematics and science foundations (Reddy et al. 2016a). The National Planning Commission (2012) notes that the country 'has embarked on an inclusive economic development pathway dependent on science, technology and innovation for which mathematics and science competence are necessary for social and economic progress'. However, as Reddy et al. (2019) argue, the poor performance in reading mathematics and science for South African children seems to continue unabated as witnessed routinely in achievement studies, particularly the Annual National Assessments; Southern African Consortium for Monitoring Educational Quality; Progress in International Reading Literacy Study; and Trends in International Mathematics and Science Study. It is clearly evident that marginalisation within a racially and class-based society results in the majority of children living in disadvantaged socio-economic communities where they are unlikely to start, progress or complete schooling successfully because of contextual and personal challenges:

> These challenges are exacerbated in the science related subjects where more individual and social resources are needed to support learners through the challenging curriculum and content. The reasons for these achievement patterns are complex and multi-dimensional and go beyond simply household incomes. (Reddy et al. 2019, p. 170)

It is imperative that any evaluation or commentary on the achievement of children, as witnessed often with the sensationalism created by the media would be limited if it ignores the devastating effects of racial marginalisation, social norms, inequalities and lack of individual freedoms, together with class-based power structures that are explicitly or implicitly responsible for the poor achievement scores. Van der Berg (2008) accurately notes that socio-economic inequalities at the school level play a role in the educational outcomes, as learners in quintile five schools outperform schools in the four lower quintiles substantially. Interestingly, none of the achievement studies are disaggregated by race and class, which would indicate that the lower quintile schools only accommodate poor black children.

Learner performance in South African schools

A noteworthy factor in performance among learners, particularly evident in subjects such as Natural Sciences, Mathematics and English, is the disjuncture between the medium of instruction in schools which is English, with the exception of some Afrikaans language schools, and the languages that children use for communication at home. We also maintain that we need a broader understanding of literacy to interrupt the reproduction of inequality and poor scholastic achievement as tests like the PIRLS and the Early Grade Reading Assessment (EGRA) conceive of reading in a narrow manner and are underpinned by a view of literacy as a measurable and quantifiable set of skills. Far too much emphasis in the teaching of literacy relies on activities with almost no intellectual demands (Chetty 2019), knowledge of phonemes, choral reading and repetition of words, which result in 'psuedo-reading' where children 'mouth' words without understanding what they are reading. Abdulatief et al. (2018) argued that in the whole language approach, learning to read was not equated with the reading of words but rather with making meaning from whole texts and pertinent to Science, Technology, Engineering and Mathematics (STEM) is knowledge of the language of science that is absent from early grade reading programmes:

> Despite the assumption that they have learned 'to read' by the end of Grade 3, children will not yet know, for example, how to read a science text without being taught how language is used in science texts and how Science texts work. Their existing knowledge of how stories (narratives) work with setting, characters, conflict and resolution will not help them to understand how texts work in other subjects across the curriculum. (Abdulatief et al. 2018, p. 7)

Language proficiency is a major factor in mathematics achievement. For example, Prediger, Wilhelm and Büchter (2018) found that language proficiency was more strongly related to mathematics achievement than social factors such as socio-economic status and immigrant status. However, language proficiency, itself, is influenced by SES. For example, Pungello et al. (2009) found that expressive language development was slower among children of lower SES families than that of their higher SES counterparts. In addition, mathematics proficiency provides the foundation for future learning in mathematics, science and technology. Therefore, 'Mathematics forms the conceptual scheme on which modern science is based and which supports technology, with close interactions among them' (Vázquez 2001, p. 1). These studies highlight the complexity of improving STEM attainment in marginalised communities.

Another factor for consideration is the preference for class-based teaching (or whole-class teaching) instead of subject specialist-based teaching in the intermediate phase (Grades 4, 5 and 6). This means that the class teacher teaches most, if not all, subjects to her class instead of having subject specialists teaching subjects such as Mathematics, Natural Sciences, Human and Social Sciences and Languages to learners. The thinking here is that the class teacher would be able to deliver the curriculum to learners in a much more integrated and meaningful manner. However, teacher education courses do not prepare depth in pedagogical content knowledge across the many primary school subjects in the curriculum. Therefore, many teachers do not have the intellectual resources to effectively teach all the intermediate phase subjects to learners. This is another instance of the disparity between the initial teacher education provision and the practice of teaching in South Africa, which does not bode well for laying the foundations of mathematics education. Consequently, marginalised learners are most severely affected because they cannot afford extra private support to fill the gap caused by ineffective teaching in subjects such as Mathematics and Natural Sciences.

It is a very sad indictment on the education system in South Africa that still relegates historically disadvantaged children to schools without basic infrastructure such as toilets, water and electricity and lack of teaching resources that do not transform learning contexts for children on the margins towards print-rich environments. The literacy achievement and scholastic progress of children in poor communities cannot be disrupted if the state continues to abdicate in its responsibility to provide relevant basal readers in African languages and resources for learning. According to Equal Education's (2023) last audit completed in 2016, only 8% of public schools in South Africa have functional libraries:

> These are almost entirely situated in former model C schools which have the resources to stock and staff these facilities. Approximately 20,000 schools are without libraries, thereby denying their learners access to regular reading opportunities. (p. 1)

It is obvious that school libraries, reading corners and classroom libraries are essential to developing cognitive capacity and critical thinking skills among children through engagement with reading. The current curriculum (CAPS) highlights the integral role of projects and self-directed learning activities, but the reality is that without school libraries children struggle to find and use the information they need, and there is almost no opportunity for them to become readers and writers. For children to succeed across multiple contexts, the learning spaces like classrooms and homes require a massive amount of exposure to meaningful experiences with books, language and cognitive activities. This inequality in resource provisioning not only marginalises poor children but also reinforces the limited uptake and poor achievement in STEM subjects in high school and university. Children from middle-class homes enjoy an abundance of print materials and play with stationery and learning resources before they attend schools where cognitive activities and teaching strategies are integrally linked to texts. It is this immersion in print-rich environments that forms the core building block for good scholastic achievement. How do children name their reality with regard to this inequality? Equal Education's (2023) research noted the points listed below.

- Over 50% of learners identified school libraries as places where they would do homework and study for exams. Hence, opportunities for significant engagement with homework and high achievement in exams are lost in schools without libraries.

- A Grade 8 learner at a high school in Khayelitsha noted some of the difficulties he faces when resorting to public libraries: ‘We wait in queues and are given a few minutes to do our research. We have to walk long distances to get there and along the way there are often gangs who take our money’.
- In communities where homes lack books and quiet spaces, school libraries offer stable sites for learning. The provision of a well-stocked and appropriately staffed library will not only aid in the development of basic reading skills but instil a love of reading in our youth.

If children are not provided with opportunities to engage cognitively with reading and learning materials early in the schooling programme, it would lead to poor learning outcomes later in school and at the tertiary level, and this reinforces the marginalisation of working-class black children who attend under-resourced schools. This ethnic imbalance in terms of black children in mostly under-resourced schools has a negative effect on access to mathematics and sciences concomitant with far-reaching consequences for careers and higher education. Students with poor scores in science and mathematics cannot access the more prestigious disciplines such as engineering, actuarial sciences and medicine, as most universities require a good higher-grade pass in these subjects. This accounts for the underrepresentation of Africans in professions requiring quantitative skills (OECD 2008). Major consequences of deficient learning and teaching in STEM education are not only the poor performance in mathematics and science education, compared to other African countries at similar economic and human development levels (Tunisia, Egypt, Morocco, Botswana and Ghana) but also a major shortage of human capital in key areas of social development that lead to constraints for enhancing South Africa’s growth and reducing unemployment (Hausmann 2007).

The focus on improving learner achievement in STEM subjects is crucial in trying to address the pervasive poverty and social inequality in countries such as South Africa. However, education is more than skills-and-knowledge impartation, and it ought to be a humanising experience first, nurturing the actualisation of the ‘full’ human experience. Therefore, Moodley and Moodley (2017), in emphasising the importance of holistic education, caution that in addressing the literacy and numeracy crises in South African basic education, we should not forget that learners are humans first.

Mathematics, science and technology through policy

Post-1994, South Africa is characterised as revolutionary in almost every part that seems necessary to emulate democracy, including education.

As such renewed policies were adopted, amended and implemented to give rise to equal opportunities through education to balance the deficits in the education field for subjects in mathematics, science and technology that was underscored for black South Africans. Authors such as Adler and Setati (2005) and Spaull (2013) echo this in noting that the provision of quality mathematics education programmes was stratified according to race to ensure socio-economic inequalities among various population groups under the pre-1994 apartheid rule. The White Paper introduced in 1995 highlighted the high attrition of mathematics and science subjects in African schools as:

> *[A]* special case because apartheid education has led to a very small number of African teachers graduating from colleges and universities in these subjects; and that 'a cycle of mediocrity' was being perpetuated through the efforts of these poorly skilled teachers in the classroom. (Department of Education [DoE] 1995, p. 19)

Likewise, the apartheid government used subjects in mathematics, science and technology as gateway subjects to deny the black population access to opportunities that come with successfully passing the subjects (Adler & Setati 2005; Spaull 2013).

Transformation in educational policies in South Africa was the immediate solution to obviate the long-standing oppressive grip that inhibited career and lifeworthy opportunities for the majority of black people, including teachers. The aim of this radical transformation was to also produce new teachers who meet these transformation ideals (Parker 2006). Consequently, the post-apartheid government implemented a series of policy initiatives to ensure both equality and equity in mathematics and science through an increased provision of qualified teachers to all schools post-1994.

> These include the introduction of the National Policy Framework for Teacher Education and Development in South Africa which aimed at addressing teacher development and the shortage of qualified teachers in the subjects of mathematics, science, and technology. (Department of Education [DoE] 2007, p. 13)

Further, in South Africa, the national curriculum is guided by the CAPS, which provides a prescribed set of topics, content and assessment criteria for each grade and subject (Letshwene & Du Plessis 2021). This is no different for the mathematics, science and technology subjects offered in schools. As such, science and mathematics teaching and learning fall under the national programmes of STEM education that are seen as a pathway to economic growth, job creation and technological advancements for countries (Tsakeni, Munje & Jita 2021).

Mathematics, science and technology teacher support

Science and mathematics education is characterised by learner under-achievement in most secondary schools (Tsakeni et al. 2021) despite the CAPS document offering a guideline for teachers on what to teach, when to teach and how to assess. Researchers suggest that there are many challenges inhibiting teachers' abilities to turn around the status quo in mathematics, science and technology teaching and highlight internal challenges that are context specific, as well as external challenges, educational policies and interpretation of policy tenets that are also to blame for implementation challenges (Tsakeni et al. 2021).

As a remedy, scholars accentuate that teacher support is a significant element in the education systems across the world (Nkambule & Amsterdam 2018; Nomxolisi, Chiphambo & Mashologu 2021) to enhance teachers' capabilities to teach. A study by Nomxolisi et al. (2021) highlighted the outstanding role the South African government is playing in supporting teachers in science subjects. Interventions and efforts from various government departments such as the Department of Science and Technology (DST) and the DBE are responsible for enhancing skills in mathematics and science (Mbowane, Devilliers & Braun 2017). Although DST supports science through, for example, the Eskom Expo for young scientists and enriches science for fair events, Mbowane et al. (2017) stress the use of science events that add value to teachers' pedagogical content knowledge. The authors also reference another stakeholder that plays a tremendous role in supporting science teaching and learning and is called the National Education Collaboration Trust (NECT). This organisation provided support to teachers to complete the curriculum at the correct pace and grade level using a tracker (Curriculum Instruction G03/2017). A tracker template contains CAPS concepts and activities, weeks with lessons and topics from the CAPS policy document with page numbers and a date to complete the lesson (Nomxolisi et al. 2021).

Although the efforts of government and district officials for curriculum implementation are commendable, their visibility and lack of follow-ups are under criticism (Tsakeni et al. 2021). The authors also suggest that:

> *[T]*eachers face individual challenges that obstruct efforts to enhance teaching and learning in Science and Mathematics. It is argued that teacher individual engagement with lesson planning, excessive workload, and the lack of/or inadequate professional development opportunities hinder teachers' ability to enhance teaching and learning of Science and Mathematics. (Tsakeni et al. 2021, p. 1302)

Further concerns raised included the issue around the deployment of teachers and suggested that there is a tendency in some schools to allocate qualified mathematics and science teachers to subjects they are not qualified to teach to accommodate Funza Lushaka Bursary graduates who must get employment because of the bursary obligations to the DBE.

Intersectionality and marginalisation in Science, Technology, Engineering, the Arts, Mathematics and Entrepreneurship

Examining the interconnectedness of differences such as race, class and gender is central to intersectionality. 'Relational thinking rejects either/or binary thinking … [i]nstead, relationality embraces a both/and frame' (Collins & Bilge 2016, p. 25). Thus, instead of focusing on the difference in silos, the framework focuses on their interconnections. Within intersectionality, all of these concepts – power, relationality and social inequality – are thought of within their particular social context. 'Using intersectionality as an analytical tool means contextualising one's argument, primarily by being aware that particular historical, intellectual, and political contexts shape what we think and do' (Collins & Bilge 2016, p. 26). These different concepts, which are woven together in the theory of intersectionality, introduce an element of complexity; thus, a theory filled with complexity can be used to understand and analyse complex systems in the world. Social justice is at the very core of incorporating an intersectional framework.

Given the unequal access and opportunity for marginalised children in South African schools discussed above, it is evident that such marginalisation persists in STEAME classrooms. The context of the basic education system shows that poor children are racialised beings, located within class and trapped in inequality. They are marginalised in mathematics, science and technology and the arts. Although research in STEAME is limited, we argue that this interconnected system of race, class, poverty and gender shapes and structures the lived experience of accessing and participating in STEAME classrooms for marginalised learners. The constant rejection of access to economic, social and political spaces has also been pushed to the margins of research niche areas within academia. Concepts such as intersectionality address the need that the marginalised 'Other' have to articulate their experience of being rejected and lack of opportunities for meaningful participation. Intersectionality enables us to acknowledge, understand and explain the complexities that are associated with the lives of the marginalised. For these same reasons, intersectionality is a lens through which to understand marginalisation in STEAME. We argue that, through voice, learners have the opportunity to project the essence of life on the margins. Voice enables empowerment in the way that it is managed by teachers and the ways in which learners use it to move from the margins to the centre (Hendricks & Lewis 1994).

Voice

In a study on understanding marginalisation in education, Messiou (2006) argues that in order to make school classrooms more inclusive, the voices of children should be used as a strategy towards inclusivity and should also be used as a manifestation of such. Messiou (2006) highlights the importance and power of foregrounding children's voices and by doing so, capturing their views and meanings of the world. The current marginalisation of poor children in South African schooling and our argument of their further marginalisation in STEAME position our narrative that capturing the lived experience of learners through 'voice' could make a difference in these classrooms. Providing space for the lived experience of the marginalised 'Other' in the centre of STEAME programmes and curricula is an effort towards decolonisation. Too often, when the marginalised gather the courage to speak, no one listens. However, as they courageously speak in minorities, they end up silenced, because no one cares to hear (Hendricks & Lewis 1994; hooks 2014; Moton & Blount-Hill 2022). Writing about the lived experience of marginalised children in STEAME, from their own perspectives and as told by their own voices, is critical to their representation. Through this process, their questions, concerns and knowledge are shifted from the margins of society to the centre and from the periphery of academic research and the production of new knowledge, to the forefront (hooks 2014; Moton & Blount-Hill 2022).

Through their own voice and perspective, the marginalised 'Other' can also be empowered. Empowerment for the marginalised cannot be bestowed by others, and it is a self-realising project as there are far too many examples of patronising attitudes towards the subaltern or neoliberal approaches to social development. Empowerment is about recognising inequalities in power, asserting the right to have rights and acting to press for and bring about structural change in favour of greater equality. Empowerment has been defined as 'control over material assets, intellectual resources and ideology' and empowerment as 'the process of challenging existing power relations, and of gaining greater control over the sources of power' (Batliwala 1994, as quoted in Cornwall 2016, p. 343). 'Empowerment can also be seen as the right to belong, to be included. It is the owning of space as active citizens and not necessarily as [dependant] subjects' (Erickson & Faria 2011).

> A key component of empowerment is for citizens to develop self-esteem so those in positions of formal power do not need to evaluate or act upon them: by developing self-esteem, citizens enact power themselves, and the state does not have to do so. (Erickson & Faria 2011, p. 639)

Voice enables learners to represent their own interests, thoughts and ideas. It occurs both psychologically and through the spoken word

(Johnson-Bailey & Lee 2005). Learners must be able to openly express themselves and reflect on their personal experiences. These reflections should be used to connect with the content taught in the STEAME classroom. Teachers have a responsibility to create an environment in which such expressions and meanings through voice are encouraged and utilised (Johnson-Bailey & Lee 2005).

Conclusion

Given the inequality still pervasive in South African schools and the enduring legacies of racialised and class intersections, creating and encouraging 'voice' could bring about access and participation for marginalised learners in STEAME. Foregrounding the voices of children is thus crucial to including the marginalised in these subjects.

Chapter 10

The wellness of STEAME teachers[19]

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Abstract

The 21st century provides a range of opportunities and challenges for the workforce, including the fast-changing technological infrastructure that unfortunately further exacerbates the divide between resource-rich contexts and contexts of poverty. The schooling system in South Africa is a microcosm

19. Certain sections of this chapter are based on the author's PhD thesis: Setlhare-Kajee (2018). The entire chapter was reworked by more than 50%.

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of this global reality, with our dual economy. Herein lies the opportunity for the education sector. Technology is important for enhancing Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) learning, for providing learners with skills to succeed in the future. This places tremendous pressure on the STEAME teachers working in under-resourced contexts. In this chapter on the wellness of STEAME teachers, we explore the potential for developing a possible wellness framework as part of the Department of Basic Education's aim for modernising and strengthening the South African school curriculum, thereby potentially addressing the unemployment reality within our communities. Education within the STEAME stream is important for critical thinking and literacy in the language of the 21st century. Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education is important for the literacy of the current schooling generation in the context of evolving industries and careers. Furthermore, it is important for changing the trajectory of underprivileged communities. Unemployment statistics among the age group of 18 to 25 years are of national concern. The potential of actioning the STEAME curriculum to fill the skills gap can be linked to Sustainable Developmental Goals (SDG), particularly the 3rd and 4th goals. The professional career identity and wellness of STEAME teachers needs to align with the question: 'Why did I become a teacher?', in the face of current intersectional realities of disenchantment and stigmatisation of the teaching profession, with the aim of promoting education with foresight about the future to work towards a society for success. We start this chapter with a brief description of wellness of teachers in relation to local and global teacher challenges related to discipline, resources, competence, safety, etc. The future proofing of teachers, guided by a critical transformative paradigm, will inform our offering of integrating Amartya Sen's Capability theory with Maslow's theory for exploring the professional identity and purpose of STEAME teachers, as linked to a life design process from career psychology. Participatory action learning and action research (PALAR) principles and skills for lifelong learning are suggested for the pre-service curricula, to align with the characteristics and values of future proofing, for promoting the wellness of STEAME teachers.

■ Introduction

The term 'STEAME education' refers to teaching and learning in the fields of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship, 'typically including educational activities across all grade levels, from pre-school to post-doctorate, and in both formal and informal classroom settings' (Gonzalez & Kuenzi 2012). It is important that teachers develop mathematics and science skills, alongside reading and writing, so that children acquire a solid foundation. In addition, it is important that children be technologically literate from a very early age. Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education provides learners with a literal and conceptual space to develop their problem-solving and critical thinking skills. However, teachers are not adequately resourced and equipped for teaching STEAME in primary and high schools. This leads to feelings of inadequacy and affects their efficacy and wellbeing in the long run. The conceptualisation of wellness or wellbeing plays a fundamental role in establishing a nurturing and thriving environment for both educators and learners. To fully grasp the dynamic nuances of wellness among all teachers, we would do well to broaden our perspective beyond mere physical health and encompass a holistic approach that incorporates psychological, physical, social and spiritual aspects (Winberg et al. 2018) that motivate the STEAME teachers to achieve their career ideals. In this chapter, we will look at how their professional career identity relating to 'Why did I become a teacher?' is linked to intersectional realities. We investigate the connection between one's professional career identity as a teacher ('Why did I become a teacher?') and the intersectional aspects linked to accessing STEAME disciplines. This exploration delves into the correlation between access to resources and the critical need to 'future proof' STEAME teachers, examining these issues through a transformative lens. The unpredictability of the 21st century requires that we explore paradigms for learning and development which address complex resource-related problems, to enable people to help themselves. In this sense, we suggest a way forward that incorporates the professional and personal identities of the STEAME teacher by encouraging participatory action research (PAR) processes for social learning and knowledge generation, to enable the teacher to overcome feelings of demotivation and inadequacy and to effect meaningful and sustainable changes in their personal and professional lives (Setlhare 2021).

■ Background

While in the process of studying technology, learners are able to understand the application of certain tools or methods, most often the term 'technology' is only synonymous with computers. Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship goes far beyond computer skills, as clarified in earlier chapters in this book. Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education is important for the literacy of the current schooling generation to meet the SDG 2030 goal of eradicating poverty and thereby changing the trajectory of low- to middle-income countries (LMIC) and under-resourced communities in higher incoming countries. Unemployment statistics among the age group of 18 to 25 years are of national concern in South Africa, exacerbated by our school drop-out rate during and after the coronavirus disease 2019 (COVID-19) pandemic (Gustafsson & Deliwe 2020). Estimates show that the April/May 2021 levels were the highest rates of dropout in 20 years or as far back as the GHS (General Household Survey) has been in operation [since 2002]. Moreover:

> In November 2020, South Africa's Minister of Basic Education, Angie Motshekga, confirmed that more than 300,000 children had potentially dropped out of primary schools across South Africa over a six-month period. The Department of Basic Education's Nompumelelo Mohohlwane explained at the launch of the report that an estimated [650,000 to 750,000 of South Africa's 13 million school-aged children between the ages of 7 and 17 were not in school by May 2021]. (Mlaba 2021, p. 12)

While these statistics are bleak, the STEAME curriculum holds the potential to change this trajectory as linked to SDG, particularly the 3rd and 4th goals. Adequately equipped STEAME teachers are central to exploring this possibility, in consideration of disenchantment and stigmatisation of the teaching profession, with the aim of promoting education towards a society that is better equipped to enter the world market than we are as South Africans at the moment. The wellness of STEAME teachers in this context cannot be overlooked. The linked participatory action learning and action research (PALAR)-life design (LD) process is hereby suggested as a means of promoting agency among teachers, to rethink their role in the context of the psychosocial challenges that are experienced by their learners as well as their own personal and professional difficulties. In both the LD and PALAR processes, teachers as lifelong learners are encouraged to collaboratively explore options for addressing the identified challenges and to network for support from within their available systemic resources. In the context of South Africa's poverty-related psychosocial challenges that impact negatively on wellness and education, the PALAR-LD process with multi-layered support processes is suggested, where different stakeholders with diverse assets collaborate to enhance the wellness of all within the school community by integrating their personal and professional narratives (Setlhare 2021). It is necessary to equip STEAME teachers from primary to secondary schools in South Africa, with the capacity to promote wellness, while simultaneously focusing on promoting the shared STEAME vision and goals.

According to The National Science and Technology Forum (NSTF 2018), South Africa continues to suffer from problems in its school education system, notably in STEAME subjects. Furthermore, 'University graduation in STEAME-related courses is around 20%, contributing to a dire need for high-level skills in STEAME areas'. The discrepancy in the consistency and quality of STEAME education, across social groups is evident. It is therefore necessary to increase literacy in STEAME subjects, in order to have an increase of a skilled workforce. This will result in the rising of career opportunities in science, technology, engineering and mathematics. The more the exposure to STEAME in school, the more the students will pursue related careers. In order to create a more employable workforce, 'young people are better off studying science, technology, engineering, and mathematics subjects' (Gap, 2017). The wellness of STEAME teachers directly impacts on their efficacy for achieving the potential outcomes for the benefit of our South African context in alignment with SDG 2 (Zero Hunger), SDG 3 (Good Health and Wellbeing) and SDG 4 (Quality Education).

Defining and conceptualising teacher wellness

South African news headlines like 'Teachers are literally sick and tired' (Beangstrom 2017), 'Educator exodus: How low pay and poor job prospects push SA's teachers to seek work overseas' (Bhengu 2023; De Villiers & Degazon-Johnson 2007) and 'Teachers live in fear as schools report surge in rude, aggressive children' (Govender 2022) offer insights into the experiences of South African teachers and the challenges they grapple with concerning their wellness. This indicates that they face significant difficulties in terms of their overall wellness. Now, let us delve into the notion of wellness or wellbeing.

The concept of wellness is approached in a variety of ways. Thien and Lee (2023) adopted Collie et al.'s (2015) three dimensions of teacher wellbeing which involve workload wellbeing, organisational wellbeing and student interaction wellbeing. Workload wellbeing relates to the impact of teaching responsibilities in terms of quality and quantity, including tasks such as grading assignments, attending meetings and working beyond regular school hours. Organisational wellbeing deals with the effects of work environment-related issues, including relationships and communication between teachers and administrators, support and recognition provided by administrators and teachers' involvement in decision-making. Student interaction wellbeing pertains to the impact of teacher–student relationships, student behaviour, student motivation and classroom management on teacher wellbeing.

Researchers also distinguish various facets of wellbeing, such as physical, psychological and occupational wellbeing, or the differentiation between wellbeing in work and non-work contexts (Miner et al. 2019; Navarro-Espinosa et al. 2021). Walker (2015) discusses the idea of wellbeing as a combination of 'being' and 'doing' in ways that hold value for individuals. Ross et al. (2020) address subjective, objective and relational wellbeing.

Diener, Oishi and Lucas (2003) define subjective wellbeing as the presence of positive emotions, the absence of negative emotions and an overall sense of life satisfaction.

Arguably, the most comprehensive understanding of teacher wellness can be found within the framework of the eight dimensions outlined by Montoya and Summers (2021). This framework delineates emotional, environmental, intellectual, physical, social, spiritual, occupational and financial dimensions of educator wellbeing.

Taking all of this into account, for the purpose of this chapter, STEAME teacher wellness or wellbeing is conceptualised by examining how STEAME teachers themselves, as well as others like significant others, learners, colleagues and parents, perceive the presence of positive emotions and the absence of negative emotions within their profession. It also considers how well they relate to those around them in the educational context and, ultimately, their overall life satisfaction. A systematic review by Hascher and Waber (2021) that reviewed 98 studies on teacher wellbeing found a significant influence of teacher wellbeing on teaching quality. This underscores the critical importance of comprehending the challenges and stressors commonly faced by STEAME teachers.

Challenges and stressors faced by Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship teachers

A study by Botha (2022) that included 88 participants including science, technology and mathematics teachers focused specifically on teacher wellbeing, indicating that teachers in South Africa typically deal with challenges such as violence in schools, mental health, discipline, overcrowded classrooms, absenteeism, socio-economic hardships, parental level of education, lack of resources and unqualified teachers. Some of the challenges encountered by STEAME teachers will now be explored in greater detail.

Pressure to ensure future-proofing

The World Economic Forum's 2016 Future of Jobs report found that children entering primary school today will find themselves in jobs that do not yet exist (Theeducatoronline.com 2023). It is reported that 75% of the fastest-growing occupations will require 'STEM' (Science, Technology, Engineering and Mathematics) skills (Du Plessis 2020). This adds to the already strenuous job-related responsibilities of the STEAME teacher to ensure that they adequately prepare learners for the workplace of the future.

Lack of resources

Many schools, especially those in disadvantaged areas, face resource constraints, including inadequate teaching materials, outdated technology and other resources, and insufficient laboratory equipment (Ansong et al. 2020). The lack of resources can hinder effective teaching and create additional stress, anxiety and depression for teachers (Amzat et al. 2021; Botha 2022; Navarro-Espinosa et al. 2021).

Overcrowded classrooms

The classroom environment in South African schools is frequently characterised by large class sizes. Public schools in South Africa, including STEAME classes, commonly experience substantial numbers of students in a single class (Köhler 2022). According to a study conducted by Köhler (2022) regarding class size, it was concluded that as class size increases, there is a tendency towards poorer educational outcomes on average, with particularly pronounced effects in schools with fewer resources. This not only intensifies the challenges faced by STEAME teachers in terms of delivering effective education but also brings about behavioural issues linked to the larger class sizes (Du Plessis 2019). These behavioural difficulties further impact teacher wellbeing in a negative manner.

Heavy workload

Linked to the topic above, teachers in schools with high enrolment were found to bear a relatively higher load of teaching and administrative tasks, consequently diminishing the level of teacher wellbeing (Tayli 2014). In a study by Bantwini (2019), South African teachers who formed part of the study experience decreased morale linked to the unfavourable work environment imposed on them, along with the high teaching workload. Teachers are often under pressure to cover a significant amount of curriculum content within limited timeframes. This heavy workload can lead to stress and burnout and relates negatively to subjective wellbeing (Burns & Machin 2013; Thien & Lee 2023). Paperwork, administrative tasks and bureaucratic requirements can take up a significant amount of a teacher's time and energy, impacting time for teaching and personal wellbeing (Botha 2022).

Unqualified teachers

Teachers expected to teach in the STEAME field are often either not qualified to teach a specific phase or not qualified to teach the subject at all.

Within the South African context, a mere 23% of educators in the senior phase (Grades 7–9) hold the necessary qualifications to teach at that educational level (Departments of Basic Education and Higher Education and Training 2011). Research by Du Plessis (2019, 2020) reflects upon the experience of teachers who teach STEAME subjects but are not qualified to do so, as well as the implications thereof. Specifically, the fact that unqualified teachers are not able to adequately respond to the diverse learning needs of the learners in the STEAME classroom comes up, which puts strain on the teacher's confidence. The teachers' inhibited capacity to manage the classroom effectively causes anxiety. In an effort to address these deficiencies, unqualified teachers often engage in in-service training or professional development courses. However, these additional activities contribute to their workload pressures, consequently impacting their overall wellbeing (Du Plessis 2020).

Student behaviour and discipline

The research conducted by Botha (2022) revealed that ill-discipline contributes to teachers experiencing feelings of being overwhelmed, powerless and anxious. Managing classroom behaviour and discipline issues can be demanding, particularly in schools facing socio-economic challenges. The South African Democratic Teachers Union (SADTU) reports that their offices handle up to 72 000 incidents of school-based violence every month (Botha 2022; Simelane 2019). These incidents refer to physical violence, verbal violence and cyberbullying and they encompass both learner- and teacher-based violence. It is with good reason that South African teachers feel unsafe while teaching. This circumstance becomes a catalyst for teachers opting to exit the profession and is a determining factor in the so-called STEAME exodus where teachers voice a likelihood to leave the profession if offered a job in a different sector (Botha 2022; Walker 2023). Teachers confronted with such challenging situations in the workplace are prone to seek better opportunities elsewhere, leading to a state of upheaval within the profession.

Support services

Social relationships (Hascher & Waber 2021) and 'connectivity' (Botha 2022) prove to be overarching factors that contribute positively to teacher wellbeing and should be the focus going forward. Teachers need positive inter- and intrapersonal interactions to sustain their wellbeing. Access to mental health support, counselling and wellness programmes may not always be readily available to educators, making it difficult to cope with the emotional demands of the profession. To contextualise the availability of support services in South Africa, the South African Council for Social Service Professions shows that the ratio of social workers to the population of South Africa is estimated at 1:5000 (Bester 2020). It is thus safe to say that assistance is not easily accessible for individuals seeking support for their mental wellbeing.

Salary

Unsatisfactory remuneration is identified by Botha (2022) as a factor that pushes teachers away from the profession. Teachers are facing heightened pressure because of minimal annual salary increases amid economic uncertainty and rising expenses (Alson 2019) and identify it as a reason why teachers decide to leave the profession or decide not to enter it in the first place (Botha 2022). Teachers' salaries may not always match the level of responsibility and effort required in their roles, leading to financial stress.

Socio-economic context

South African STEAME teachers encounter distinctive obstacles linked to the socio-economic status prevalent in many communities, largely an ongoing consequence of apartheid and ironically the massification of education for the job market (Motala, Vally & Maharajh 2018). The Teaching and Learning International Survey (TALIS) report shows that a significant 71% of teachers work in schools where more than 30% of the student population faces socio-economic disadvantages (Ainley & Carstens 2018). This statistic reflects the presence of poverty and/or inequality in South African society. These challenges pose unique barriers that are not necessarily encountered by first-world nations. Teachers in schools serving marginalised communities may face additional pressure because of challenges associated with poverty, language barriers and societal issues that impact their own and their learners' learning and wellbeing.

Future-proofing of STEAME teaching could be ensured if the wellbeing of teachers is attended to. If teachers' wellbeing is not prioritised by addressing the many challenges in a practical way, the education community may suffer long-term effects as more teachers leave the profession (Botha 2022). To prevent this and ensure future-proofing of STEAME education, it is essential to recognise and address the challenges, so as to offer ways to deal with it to lessen negative emotions and increase overall satisfaction related to being a teacher in this field. The theory that forms the foundation for suggestions on how to accomplish this will consequently be proposed.

Theoretical foundations of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship teachers' wellbeing

A myriad of literature exists on how best to prepare pre-service teachers for the realities in the field … in the end 'it's what happens in the classroom' that matters. South African teachers who are required to address poverty-related psychosocial challenges experienced by learners at school lack the skills needed to support learners (Setlhare, Wood & Meyer 2016). The development of capacity and agency to address the contextual challenges, as discussed higher up in this chapter, has to start with helping teachers understand their own personal and professional identities. We will now explore how a linked LD and PALAR, that is, LD-PALAR, process shows promise as a potential pathway for South African teachers as change agents, where the teachers collaborate to enhance their own wellness in order to effectively address the identified psychosocial challenges. We start with the theoretical lens of Maslow's hierarchy for promoting the capacity of teachers to self-actualise and thereby be better able to support learners, as they understand their own personal and professional realities more clearly. Both LD and PALAR have been used successfully with professional and social communities to encourage iterative reflection for personal and professional development towards action (Maree 2009). Both LD and PALAR encourage agency through iterative reflection on existing realities, with the aim of collaborating towards the envisioned reality of teacher wellness in the context of many 21st century (C21st) within post-colonial and post-apartheid legacies that still influence our schooling communities. These processes align with the vision and desired outcomes of the future-proofing of teachers, particularly those in the STEAME stream.

Education in the STEAME subjects lays the foundation for children for developing critical thinking and for them to be literate in the language of the future. Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education is important for the literacy of the next generation, in the sense of preparing them for evolving industries and careers. These skills, when mastered by the young generation, will be an asset for future community development when addressing local and national challenges. Furthermore, it is important for changing the trajectory of underprivileged communities linking to Maslow's Hierarchy of Needs; the Honourable Mia Mottley, Prime Minister of Barbados, at the 20th Nelson Mandela Annual Lecture in eThekwini, South Africa, on 12 November 2022 stated:

> [… *W*]e cannot talk about economic justice and economic opportunity if the basic aspects of freedom have not been guaranteed…We live in a world that is at a very strange moment in time. It has been described recently as a

> 'polycrisis'/'perma crisis', and it has been so described because as soon as you get accustomed to managing one crisis you're being hit by another one and another one and another one. (Nartey 2023, p. P1)

This speaks directly to the current dilemma that teachers, as professionals, face in terms of policy, practice and praxis. Central to this is the wellness and competence of teachers within the fast-changing 21st century. In an exploration of the wellness of South African STEAME teachers, the SDG 3 and SDG 4 are relevant considerations. Majority of programme frameworks currently used to prepare teachers in established global northern contexts do not adequately acknowledge the wider and deeper nuances prevalent in our post-colonial and post-apartheid contexts (eds. Surender & Walker 2013). Both practice and policy in South Africa still largely reflect trends that are dominant in Northern welfare states and are thus criticised for not adequately addressing local challenges such as poverty, unemployment, inequality and violence (Liddiard et al. 2007). These historical socio-economic realities did not unfold in a vacuum but were influenced by historical global events, particularly related to post-colonial economic trends. These economic and trade trends had a direct impact on society for the conceptualisation and implementation of teacher training programmes, which sought to graduate students for industry (Midgley 2013). In trying to understand the reality, we need to look at the contextual economic environment in which training programmes were shaped (Patel & Ulriksen 2018).

South Africa is a country commonly known for its high levels of violence (Sui et al. 2021), with direct negative effects on the individual and collective wellbeing and daily function (Mayisela 2018; Van der Merwe, Dawes & Ward 2013), as well as their ability to meet their basic needs, including physiological, safety, love and belongingness, and esteem needs (Gregory et al. 2020). Abraham Maslow emphasises the importance of fulfilling basic needs to achieve self-actualisation (Maslow 1943). Lack of access to basic needs can interfere with an individual attaining self-actualisation. Maslow's theory of hierarchical needs provides a framework for understanding the STEAME teacher training reality.

While it has been a historical misalignment, to directly import and transpose theories from one context and historical period, as is evidenced in traditional and modernist approaches (Pillay & Laher 2014; Setlhare-Meltor & Wood 2016), Maslow's Hierarchy of Needs provides a relevant framework for our context. This also applies to using theoretical models for teacher training programmes in under-resourced countries where there is little homogeneity, regarding the development of training programmes within the larger global south (Hall & Midgley 2004; Mares & Carnes 2009; Mkandawire 2004). By engaging with more than one theoretical approach for the current teacher training programmes within a heterogeneous

South African community, we can explore a future-proofing approach suited to the diverse needs of our complex context. The current South African reality is that educational resources are more accessible to those who have the financial means, with very little acknowledgement and inclusion of community resources. Policy regulates the provision of professional support to South African teachers, in the pursuit of wellness for all. Their infrastructure, however, is out of sync with the needs of individuals living in under-resourced communities. The reality in the field reflects an inequitable access to quality education, as espoused by the Sustainable Development Goals 3 and 4. A PALAR approach is suggested for capacitating teachers for the evolving C21st.

Participatory action learning and action research approach

The PALAR approach recognises individual and community agencies for addressing challenges, by acknowledging existing community knowledge for addressing contextual challenges (Chilisa 2012). This could potentially improve mental wellness among teachers (Pillay, Patel & Setlhare-Kajee 2023). The PALAR approach highlights relationship building for collaborative action and is based on a social transformative and emancipatory critical paradigm, where the implementation of professional learning is reflected on in an iterative process in order to continually improve professional learning and add value to existing practice (Zuber-Skerritt 2012). In the context of South Africa, teachers are not sufficiently equipped to address poverty-related challenges, as previously highlighted in this chapter, for the purpose of achieving STEAME outcomes. When universities partner with teachers as co-researchers in addressing the challenges, there are mutually beneficial learning opportunities, because the teachers are more familiar with the daily challenges of teaching and learning in these contexts. In this way, teachers working in difficult conditions are an integral part of the improvement process, while the academic researchers facilitate the process with the many resources available at tertiary institutions. The practice of PALAR in a context is complex with varying depths of one-on-one and group interactions and reflections. Relationship building is a cornerstone of the process, with regular reflection and evaluation of decisions and actions taken. This could be a strength and challenge of PALAR. Acknowledging individual and group experiences in the process ensures validity and relevance, whereas reaching group consensus requires the sharing of ideas which takes a long time, as compared to traditional research approaches of coming in with a set hypothesis as with positivist research (Setlhare 2021; Setlhare et al. 2016).

Motivation for participatory action learning and action research to address contextual challenges

From a systemic perspective, understanding the historical trajectory of events which has culminated in the unequal access to resources within the South African schooling system could be helpful for considering possible solutions to the current STEAME reality. The inclusion of current stakeholders in the process of addressing the identified STEAME challenges will add depth to the process, as the local stakeholders have insight into their unique contexts. Historical, economic, political, cultural, social and institutional factors are integrated within the PALAR approach. The United Nations first introduced the Social development approach in the 1960s to contexts where the economies were in steady progress after the devastating consequences of both World War I and World War II. Colonised African countries were affected by both these events, even though they were not decision-makers in the global political arena at the time. Our economy was therefore not growing independently at all, and social welfare structures to redress the impact of colonialism were not a priority. Indigenous values like Ubuntu were practised within communities, but not recognised in any formal structures at the time (Chilisa 2012).

Under colonialism, the existing indigenous sociopolitical order and education systems were changed by colonial authorities to meet and serve their colonial agenda of expanding their markets and need for natural resources (Patel 2011). This disrupted the existing structures for ensuring education among indigenous communities (Chilisa 2012). This reality perpetuated even after the colonies were given their independence. As colonies, African countries only started gaining independence from the 1960s onwards (Mazel 2014). South Africa had a further delay of four decades, after being under colonial rule of both the Dutch and British at different periods. The colonisers in other African countries went back to their countries of origin, whereas both British and Dutch immigrants chose to remain in South Africa and continue white domination as citizens, still in control of the economy and rapid industrialisation, which eroded indigenous social systems (Patel 2011). Apartheid policies from 1948 onwards perpetuated colonialism with far-reaching socio-economic consequences that are still evident today in our polarised communities and our education system. In this sense, South Africa was the last African country to break the shackles of colonialist practice in April 1994, in favour of democracy. The racially fragmented apartheid education systems, inherited from colonialism and perpetuated by legislation over the 40 years of apartheid in South Africa, retarded the development of any progressive practices to benefit the national equitable growth. As a nation, we currently have in place a democratically designed constitution that informs our education policies (Patel 2014). This includes the provision of education and mental health services which in turn contributes to individual and community wellness. The implementation of these progressive democratic policies post-1994 to a socio-economic context that is still healing from over three centuries of combined colonialism and apartheid presents a disconnect/social dissonance for actioning the progressive policies where communities have not sufficiently transformed from the colonial-apartheid legacy (Spaull 2013). We have a dual economy (Spaull 2013), where access to resources and opportunity for development is skewed in favour of the minority, where the majority of those who benefit are still within the white and Indian community (eds. Bhorat & Kanbur 2006), based on previous privilege and a few blacks who have had access through political affiliation post-1994 (Patel 2015). Our Gini coefficient indicates the significant inequalities still existing in the country even after policies like Black Economic Empowerment (Harmse 2006; Nkomo & Kriek 2011). The existence of two socio-economic realities running parallel in our country presents a challenge to the practice of equitable education and distribution of services and material resources (Spaull 2013). The potential benefits of the PALAR approach in South Africa are currently discouraged by large-scale financial mismanagement and the adherence to capitalist and neo-colonial values and practices (Midgely 2011). Amartya Sen's (1979) ideal of personal freedom, which is currently curtailed in South Africa by large-scale poverty (eds. Bhorat & Kanbur 2006), aligns well with PALAR, which promotes the inclusion of communities, in this case schooling communities, in collectively exploring pathways for addressing contextual challenges.

Globally, more inclusive approaches started arising in the mid-1990s when declining employment opportunities as a result of minimal economic growth simultaneously became a reality. Sen's human capabilities theory, for example, was a response to this reality. He suggested that economies would grow when people are encouraged to explore their options and choices through human capital development. With the current myriad of challenges, teachers can be encouraged, through PALAR, to start promoting their agency to achieve self-actualisation.

This process would potentially promote development, wellness and progress for all in alignment with the current SDG 3 (Good Health and Wellbeing) and SDG 4 (Quality Education). Participatory action learning and action research emphasises the role of critical transformation in promoting professional and personal wellbeing and recognises the vital importance of human agency and diverse institutions in bringing this about. Critics of the approach question the practical processes and time frames for achieving these ideal outcomes. According to Midgley and

Conley (2010), these critics do not consider the contribution of investment strategies with communities that mobilise local communities to be part of projects designed to improve local conditions.

In South Africa, the 17 SDGs aligned well with our constitution and Bill of Rights which aimed to redress the past imbalances that are still very evident in under-resourced township communities, particularly with regard to the provision of basic services, like education. Meaningful change can only be achieved when the social structures that perpetuate poverty, inequality and oppression are challenged and ultimately dismantled by ordinary people (eds. Choudry, Hanley & Shragge 2012). The recent trend towards decolonising history suggests that pre-colonial education practices in Africa and South America did not follow conservative paternalistic trends. Rather, socio-political structures were more inclusive and egalitarian, so that the practice of care was part of the social structures and processes and was related to an economic or market value (Chilisa 2012).

Participatory action learning and action research offers a possible opportunity for integration with indigenous/existing knowledge systems and community psychology to guide us towards better wellbeing of teachers. With the world's wealth concentrated in the hands of a few multinational corporations (Patel 2015), communities need to collaborate and engage around ideas for how individuals, families and schooling communities can jointly address the identified contextual challenges. The PALAR approach advocates involving community members in addressing contextual challenges from an inclusive and emancipatory stance, taking into consideration that each context is unique (Midgley 2013; Prilleltensky 2010). Well-being is 'a positive state of affairs, brought about by the synergistic satisfaction of personal, organisational and collective needs of individuals, organisations and communities alike' (Prilleltensky & Prilleltensky 2006, p. 12), as opposed to under-resourced or disadvantaged realities.

■ Life design

With the LD process, personal life narratives are integrated (Rehfuss & Di Fabio 2012) by deconstructing previous and current life experiences for iterative purposes to plan future personal and professional narratives. The LD process in career psychology is not merely about career trajectories, but encourages synergy with life narrative to provide the 'golden thread' (Savickas 2011a, p. 25) to guide future decisions (Di Fabio & Maree 2012). The aim of the LD process is to collaboratively facilitate an optimal ending for a reconstructed life narrative. The LD practitioner facilitates the reflections on future sustainable options by prompts in the form of purposeful questions to encourage the individual towards crystallised ideas for the way forward and to take conscious action to achieve the newly identified life goals of their newly constructed life narrative. The implication is that a reflective and iterative LD process with South African pre-service teachers in all subjects, including STEAM, may be beneficial for assisting STEAM and other teachers establish their purpose and goals in spite of contextual professional obstacles and personal challenges.

Way forward[20]

The PALAR-LD process could be introduced to pre-service teachers. The LD process would encourage new teachers to hold onto their personal goals and purpose by integrating the past and current narratives to guide their way forward as emerging professionals. Participatory action learning and action research could equally be part of continued professional development to continually improve teachers' practice and to move beyond feelings of inadequacy and low efficacy in responding collectively to contextual challenges. As future teachers who are faced with unpredictable 21st-century challenges, STEAME teachers are encouraged to promote personal and collective agencies by including local knowledge and assets in order to be relevant to our communities. The suggested PALAR-LD process integrates the experiences of local participants to create new knowledge and to integrate with existing empirical knowledge and thereby encourages access to knowledge, which was previously denied by traditional, positivist professional and academic processes.

Practical recommendations for ensuring the wellbeing of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship teachers

On a daily practical level, Baloglu and Kocak (2006) suggest ways of providing support to teachers: Firstly, it is important that the school management and wider school community recognise what teachers have been doing well throughout the year and not only at a once-off meritocratic awards evening. In that way, they provide sustained positive feedback so that the teachers can be confident in what they are doing. At school, staff and learners can be capitated with stress management techniques and coping mechanisms. Staff members can be reminded to be cognisant of the signs of low self-esteem among their colleagues. The school could offer support to teachers by offering mentorship programmes

20. Parts of this section are based on Setlhare (2021).

to them. Overall, mental health programmes in schools are beneficial to all teachers and should not be the domain of Life Orientation teachers only. Fairness within the school system related to workload distribution and reasonable extracurricular responsibilities need to be prioritised to encourage teacher wellness. It is vital that teachers who are experiencing anxiety symptoms open up and request support from colleagues as well as from professional psychologists when required. School should be a supportive environment for such teachers.

Conclusion

The focus of this chapter has been on contextualising wellness within STEAME to capacitate these emerging professionals to address psychosocial challenges that are not related to challenges only, but also to individual, collective and systemic assets:

> Future work in schools where the PALAR-LD methodology is used could monitor learners' motivation, academic performance and holistic wellness, [in order] to gauge whether the linked process may be of benefit to children and adolescents in contexts where there is a dire need of mental-health interventions. (Setlhare 2021, p. 18)

Chapter 11

The infusion of arts and entrepreneurial thinking in STE(A)M(E) education: Opportunities and challenges[21]

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21. Parts of this chapter represents a substantial reworking (more than 50%) of Booyse (2010)

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Abstract

Arts and entrepreneurship (A & E) have only recently been added to the Science, Technology, Engineering and Mathematics (STEM) acronym to create Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME). This in part was done in recognition of the need to broaden the conception of science and mathematics education in South Africa to address both the potentially humanising influence of the arts and indigenous knowledge and the pressing need to impact on youth unemployment which is over 60% (Stats SA). In a country such as South Africa, with an unacceptably high unemployment rate, the development of an entrepreneurial mindset in learners should be encouraged. This chapter explores such an entrepreneurial focus in the STEAME curriculum, and especially the affordances of indigenous knowledge to enhance entrepreneurship. Indigenous knowledge research could potentially open up many entrepreneurial and career opportunities for learners, and care should be taken to not simply exclude indigenous knowledge because of its (sometimes) metaphysical dimension, which is seen as being in contrast with the empirical and objective nature of the natural sciences. Consideration is given to the contextual background of A & E in schools and colleges using a constructivist and cultural-historical activity theory (CHAT) theoretical framework. The chapter addresses examples of good practice as well as looking at challenges and opportunities for the inclusion of A & E in the science, engineering and mathematics curriculum. The chapter also highlights the affordances and implications of this in pre- and in-service teacher education.

Introduction

As a precursor towards problematising the current arts and entrepreneurship in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME), it may be useful to reflect briefly on concerns evident in the literature pertaining to entrepreneurship education and graduate employability nearly two decades ago:

> Much of the literature has not yet directly linked work on entrepreneurship education pedagogy and the employment of graduates; in the past research has typically [focussed] on its link with venture creation. (Pittaway & Cope 2007, p. 497)

It would seem, therefore, that the graduate labour market prevails as a key influence for studies in this area, taking into account that the systematic literature review conducted by Pittaway and Cope at the time offered the following insights for future research. There is uncertainty about:

> [*W*]hat 'entrepreneurship education' actually *is*, policy is generally unclear about what outputs are to be created when such education is promoted; and, even if these policy questions were resolved we do not know what works and to what end. (Pittaway & Cope 2007, p. 500)

The latter authors recommended that government investment in this domain should ideally focus on improving the evidence base towards appropriately framed policy work matched with clearly identified contexts for doing effective work in STEAM.

From the literature, it would appear that the A & E in STEAME might continue to take root unevenly across higher education landscapes. Solomon et al. (2002) concluded that pedagogy is changing based on a broadening market interest in entrepreneurial education in the United States of America (USA). New interdisciplinary programmes use faculty teams to develop teams for non-business students, and there is a growing trend in courses specifically designed for art, engineering and science students. More recently, and specifically regarding the A & E in STEAM, although the literature confirms that arts entrepreneurship is 'not a new area of investigation' (Rivetti & Migliaccio 2018, p. 11), it would seem that renewed scholarly interest currently addresses more complex matters pertaining to identity as a key and common area of engagement across several fields of study. For ongoing engagement, the following main sub-themes emerge from the literature on the entrepreneur in the arts: '[...] the culture-business relationship, the similarities between the artist and the entrepreneur, and the idealized arts entrepreneur' (Rivetti & Migliaccio 2018, p. 16).

The complexity of STEAME, as a nascent and evolving field, continues to attract scholarly attention. For example, a recent paper critically analyses STEAM as it broadly seeks to understand how it could best be embraced as a vision and a practice. Mejias, Thompson, Sedas, Rosin, Soep, Peppler, Roche, Wong, Hurley, Bell & Bevan (2021) indicate that:

> Among recent calls to return to humanities and to integrate arts and humanities into STEM (NASEM 2018), it is necessary to consider what is possible with transformative STEAM approaches as they increasingly become framed as contributing to improved educational outcomes. Articulating a typology of STEAM [*rhetoric*] offers a means to clarify and further probe the transformative potential of STEAM, in light of its contemporary usages and aspirations [(*Mejias et al. 2021, p. 225*). *The authors also invite the building of*] *'new cross-disciplinary* [*epistemologies*] of arts and STEM' [*noting that*] 'these approaches to STEAM may hold significant potential to increase efforts to [*decolonise*] learning spaces, elevate indigenous knowledge, and [*prioritise*] equity as policy means and ends (Land 2013; McCarthy et al. 2004; Root-Bernstein et al. 2011). (Mejias et al. 2021, p. 226)

However, the literature also points to critiques of STEAM-based education, noting detractors in several directions. There are critics of STEAM education who hold the view that it is a time distraction to include the arts with Science, Technology, Engineering, Mathematics (STEM) in that the inclusion prohibits a 'scientific exploration of maths, science, technology and engineering' (Belbase et al. 2022, p. 2939; Rabalais 2014). Other scholars argue that there are insufficient expert teachers who 'understand STEAM education's nature' (Belbase et al. 2022, p. 2939). Crucially, there are still concerns pertaining to the meaning of STEAM education:

> [*B*]ecause of the terminology associated with STEAM such as multi-vocal, multi-perspectival and complex, which has created a discontent among various stakeholders in regard to the content and manner of STEAM in education [*in*] schools (Colucci-Gray et al. 2017). (Belbase et al. 2022, p. 2939)

To this end, scholars such as De Avila and Davel (2023) propose a typology of arts entrepreneurship for us to consider based on four main anchors: innovation, mindset, project and organisation (De Avila & Davel 2023, p. 6). These can be described as follows:

> *Innovation-based arts entrepreneurship* has a transformative foundation that could potentially assist in creating new markets or substantially changing them.
>
> *Mindset-based entrepreneurship* fuels the artistic process and renders the creative process as the beginning of a value chain in which entrepreneurship makes artistic ideas tangible.
>
> *Project-based entrepreneurship* can accommodate the view that a large number of artists can act as self-employed professionals and be entrepreneurially self-reliant.
>
> *Organisation-based entrepreneurship* offers an opportunity for small or medium-sized co-operatives, dance companies or large audio-visual production companies to offer cultural goods and services to the public.

■ Methodology followed in this chapter

This chapter utilised literature review as a systematic way of synthesising previous research and integrating findings and perspectives, '[...] to show evidence on a meta-level and to uncover areas in which more research is needed' (Snyder 2019, p. 333)

The STEAM education discourse, advocating for the infusion of arts, started as early as 2006, yet the past two decades' discourse did not result in an established and robust body of research (Marín-Marín et al. 2021), or even agreement among science educators for its inclusion. Arguments against the infusion of arts in science education include epistemological and ontological considerations, for example, that science education should build on the tenets of science, and arts is characterised by different tenets. The authors of this chapter disagree with the latter. Fulton and Simpson-Steele (2016) highlight the alignment in the processes of the natural sciences and arts, as both fields require discovery, observation, experimentation, analysis, interpretation and evaluation. For this reason, a literature study 'has the capacity to engender new ideas and directions for a particular field' (Snyder 2019, p. 339), and for this reason, the authors decided upon a literature review, enriched with a number of case studies.

The historical contexts of arts and entrepreneurship in schools and colleges[22]

It is noted from the literature (Belbase et al. 2021) that an increasing number of schools and colleges particularly in the USA have incorporated STEAM pedagogy into their curricula 'to bring marginalised and underrepresented communities into the inclusiveness and justice in pedagogy' (Belbase et al. 2021, p. 2922). European, African and Latin American countries are also promoting STEAME education at the school level through different programmes (Belbase et al. 2021, p. 2923). Many European states are implementing various strategies in order to promote STEAME education (European Schoolnet 2018). For example, Denmark has a policy in place, which aims to increase the number of students who are interested in STEM programmes in school.

In African countries, STEAME education initiatives have been developed as a means of empowerment and equity, especially for women and girls (Women Entrepreneurs for Africa 2020). The programme launched by Women Entrepreneurs for Africa (We for AFRICA) aims to empower girls and women through several programmes, for example, developing community libraries to support STEAME education and helping to develop microlevel enterprises. Likewise, Inspire Africa is a STEAM programme launched in schools in South Africa that integrates drone technology with science, engineering, mathematics and arts (Kruger 2019), and the STEAM Foundation non-profit company (NPC) is promoting STEAM education in South Africa through educator training, manufacturing and distributing instructional materials, and researching on STEAM issues (STEAM Foundation, NPC 2020).

However, it is a formidable challenge to address *the historical contexts* of A & E in schools and colleges without giving due attention to the important question posed by Belbase et al. (2021, p. 2940): What form of the arts does STEAM represent?

There appear to be widely divergent views on the nature of the arts integrated into STEM. While some scholars consider it to be the visual part (painting, drawing, photography, sculpture, media arts and design), others view it as visual, performing (dance, music and theatre), digital, media, aesthetics and crafts. And still others argue liberal arts and humanities disciplines could be accommodated within the definition (Belbase et al. 2021, p. 2940).

22. The following section is based on the published material: Belbase et al. (2021, pp. 2919–2955). https://doi.org/10.1080/0020739X.2021.1922943

Without definitional clarity and a common working definition of 'arts' going forward, a present attempt at a historical context of A & E in schools and colleges could become a Labyrinthian task, and more carefully defined parameters could usefully assist such an undertaking.

Examples of practice: Infusing arts, entrepreneurship and indigenous knowledge systems

The previous section focused on the historical context of arts and entrepreneurship in schools and colleges. Authors have alluded to the challenges of implementing art particularly as a subject in schools (e.g. Daugherty 2013). Arts and entrepreneurship have been offered in various forms at schools and colleges. For example, in public schools, art has been offered as a subject though with declining emphasis and numbers over the decades. The decline has been especially prevalent in poorer and under-resourced schools. The same applies to music, dance and drama unless the school is defined as an 'Arts focus' school where the state then supports the identified school with the requisite funding and staff. At some high schools, art is offered as an additional subject at additional cost, unless the high school has a dedicated art class. Combining arts and entrepreneurship has been linked to market days offered at various institutions.

At Technical and Vocational Education and Training (TVET) colleges, the arts is confined to graphic design, and if available, music, dance and drama are confined to college bands and choirs. With college emphasis on primarily engineering and business streams, art is either under-resourced or does not exist.

Over the years, there have been various initiatives where the A & E has been used to empower youth. In this section, we will briefly look at initiatives at the school level, in a TVET context, in an Adult and Community Education and Training (ACET) context and in teacher education (higher education institutions [HEIs]). It is argued that infusing the STEM disciplines requires artistic thinking, which will help to ensure that the design appeals to the aesthetic sense of consumers in the products created for the commercial market.

Case study 1: School contexts[23]

Although taught separately from the sciences, art is increasingly seen as an important contributor to developing critical and creative thinking. In their

23. Parts of this section are based on the published work: The UWC Science Learning Centre for Africa Art Competition (2023).

study, Bequette and Bequette (2012) put forward the argument from educators that artistic and creative processes become part of STEAM education. The authors contend that this may allow for increased prominence of art education and STEM learning for heightened student engagement. The authors, however, note that this may weaken the boundaries between the disciplines and the boundaries between the different pedagogic approaches.

Scholars have argued that the arts have often been unfairly looked at as being an elitist and lacking relevance in the context of the society. Daugherty (2013), for example, highlights that many schools consider the arts as special subjects to be pursued by a privileged and talented few students. However, an increasing number of authors have argued that infusing art in STEM has advantages.

Storksdieck (2011) puts forward two arguments for the increased use of the arts in education. In the first argument, he refers to art as a way of knowing and learning that will expand the competencies of STEM. In this context, he argued that art can be useful in engineering as companies attempt to make products and systems more useful to people. Furthermore, Storksdieck (2011) argues that within science, art can allow for a different means of seeing and understanding the world. Exploring these alternatives through the use of art involves experiential-based discovery and action, which results in a refocus of attention and search for alternatives (Kheirandish & Mousavi 2018). The effect of art infusion in thinking and focus could bring about a higher level of mindfulness that promotes increased creativity, flexibility, effective information usage and memory retention (Ritchhart & Perkins 2002). Being mindful furthermore assists individuals in feeling more in control of their lives, being able to self-regulate actions and being more able to stay longer on a problem in order to effectively solve the problem. Self-regulated learning also entails ways for learners to monitor and evaluate their own learning for self-feedback and be able to value their own work and that of others (Booyse 2017). As a result, the actual educational potential of mindfulness is in its capacity to address certain difficult problems in education including the flexible transfer of knowledge and skills to different contexts, promoting deep understanding, inner motivation and engagement, critical thinking and creativity, and the development self-directed learners (Armstrong 2019; Leverette 2022; Rechtschaffen 2014). The need to focus on the effect of self-directed learning is linked to research that highlights the necessity to promote learner control and agency of the learning process (Dron 2007) in which learners adapt their mental competencies into task-related skills (Zimmerman 2001). This is the process that learners utilise to manage and organise their thoughts and change them into competencies used for learning.

Yet, for self-regulated learning to materialise, there is the need to be able to choose and personalise from the available content and tools, as well as to provide the pertinent scaffolding to aid learning (McLoughlin & Lee 2009). This means that the role of the teacher is important to guide learners in the execution of learning activities that engender knowledge production, understanding and high-order learning (Stubbé & Theunissen 2008).

The second claim made by Storksdieck is based on the limitations of scientific research and engineering design. Art, in his view, is a means to open the mind of the scientist and engineer and infuse creativity and innovation (2011). This level of creativity and innovation is then seen as equally important to understanding and applying science and engineering concepts outside the boundaries of those professional fields. Art-based instruction could allow students who have no particular interest in becoming an engineer or scientist, to understand and apply these concepts more readily to other areas.

An example of an art centre that also serves as an art school for the surrounding high school is the Peter Clarke Art Centre.

It is stated on their website that the centre, together with their Ibhabhathane Project that targets under-resourced schools and communities, aims to provide visual art and design education to learners and educators of varying abilities, within an 'inspiring, vibrant and nurturing environment'. Furthermore, the website notes that the centre specialises in teaching the visual arts and design within the Western Cape Education Department's (WCED) curriculum (https://www.pcac.co.za/). Although the focus of the centre is on completing the school curriculum, entrepreneurship through regular market days is evident. However, the centre as with other art schools is focused on the visual arts and not the sciences.

The University of the Western Cape (UWC)'s Science Learning Centre for Africa (SLCA) provided another example of infusing the arts into STEAME education. School learners in the Western Cape province were invited to submit artwork for National Science Week on 05 August 2023, in which they indicated how science, mathematics and technology influence our daily lives. Such approaches firstly facilitate the border-crossing between science and our daily lives, highlighting science-and-society approaches (which is emphasised in the Curriculum and Assessment Policy Statement [CAPS]). Secondly, there is also border-crossing between two different bodies of knowledge, namely, scientific knowledge and the arts. There are a number of shared tenets between the natural sciences and the arts, for example, both require discovery, observation, experimentation, description, interpretation, analysis and evaluation (Fulton & Simpson-Steele 2016). In Figure 11.1, some of the artwork of the learners are shown (printed with permission).

Source: Western Cape school learners' artwork submitted for National Science Week 2023 (published with the permission of the artist and the UWC's SLCA).

FIGURE 11.1: Western Cape province school learners' artwork submitted for National Science Week 2023.

The left side (Figure 11.1a) shows two astronauts from Africa having a braai on Mars, done by a Grade 11 learner, Anemi Dames; the right-hand (Figure 11.1b) is an artwork done with graphite pencils, a battery eraser and graphite powder showing a woman in the universe with planets, stars and galaxies around her, done by Akudziwe Claire Chivane from Amajuba High School in Newcastle.

Cherney et al. (2006, p. 127) describe children's drawings as a 'mirror to their minds'. Research highlights that analysing children's artwork could provide insight into (1) the emotional state of the person and affect (e.g. interests) and (2) perspectives on cognition and the development of concepts (Rosenblatt & Winner 1988). Drawings could provide insight into a child's cognitive strategies, such as planning and sequencing (Freeman 1980; Rosenblat & Winner 1988). Increased complexity in children's drawings shows advancement in their working memory and spatial abilities (Cherney et al. 2006).

Güney and Seker (2017, p. 867) state that '(r)elating aesthetic aspects of science with content of science and paving the way for aesthetic experiences through artwork may enrich science education'. The infusion of arts in the natural sciences could enhance scientific literacy. Ulger (2019) also highlights the role of art expression in developing problem-solving skills and enhancing creative thinking – also essential tenets of the natural sciences.

In Figure 11.2, the power of artwork to express scientific content/concepts is illustrated. For the above-mentioned UWC National Science Week event, an artwork was commissioned by the UWC, and Will Joubert Alves, a Cape Town artist, produced a painting entitled ‘Tracing humanity’s artistic dialogue with the universe, science and mathematics through time’.

The artwork captures the artistic interpretations of science and the universe through the ages, highlighting the deep connection between art and human intellectual pursuits. The artwork depicts five dominant eras in human history: (1) Ancient civilisations, such as the Mayans and the San; (2) the Classical World, with dominant Greek and Roman influences; (3) the Renaissance, which was characterised by scientific exploration and artistic reawakening. In the artwork, Leonardo da Vinci’s *Vitruvian Man* is shown; (4) the Enlightenment, which brought much scientific progress and scientific discoveries such as microscopes and the telescope; and (5) the

Source: Will Joubert Alves was commissioned to do a painting for the 2023 UWC National Science Week event (published with the permission of the artist and the UWC’s SLCA).

FIGURE 11.2: Tracing humanity’s artistic dialogue with the universe, science and mathematics through time.

current stage, the Fourth Industrial Revolution (4IR), depicted by the image of a robot, in the era of artificial intelligence. Central in the artwork is the Khoisan. Carnarvon in the Northern Cape province is both the home of the Square Kilometre Array (SKA) radio telescope and the Khoisan. It speaks to the motto of UWC, 'Respice Prospice', looking back, looking forward. We need to learn from our rich indigenous knowledge. The San expressed their knowledge of the universe and nature through their rock art, which is also shown in the painting. The Khoisan people are scientists with a wealth of knowledge of plant use (ethnobotany). In the artwork, the *Aloe dichotoma* (quiver tree) is shown, which was used as quivers for their arrows. Also shown is the Eland, which played an important role in San belief, ritual and rock art.

Case study 2: Adult and Community Education and Training colleges

Public ACET colleges have been chronically under-resourced for a number of years (Aitchison 2003). There have therefore been no art-related learning areas offered at these colleges unless there have been specific targeted interventions. At private/NGO centres, the picture has been slightly different. Being funded with a specific mandate, these community colleges have innovative programmes to offer communities. However, sustainability has been a challenge for these colleges. At a few centres, the training of indigenous crafts as a means to develop micro-enterprises and to maintain a livelihood, particularly for poor and rural communities, has been established. An example of this has been the Kara Heritage Institute and its community development programme. Thereby:

> The Kara Heritage Institute Community Development Programme educates communities in the likes of indigenous cultural heritage and African tradition, while training them in numerous other skills. The organisation's primary goal is to shape sustainable livelihoods through skills development, assisting communities in acquiring the capabilities, assets and activities needed to make a better living. (https://www.kara.co.za/)

Case study 3: Technical and Vocational Education and Training colleges

The primary focus of TVET colleges is the training of skilled artisans for the workplace. Watson et al. (2013) argue that STEAM provides a practical and holistic paradigm that is grounded in economic need thereby ensuring more relevance to the experience and tastes of consumers. The inclusion of artistic thinking in the training of scientists and engineers helps to improve their skills to produce relevant products and services.

A study by Saiden (2017) investigated the establishment of entrepreneurial skills in the Zimbabwean education curriculum and how this is related to STEM. He found that entrepreneurial skills development in the initial stages of learning makes an important contribution to the economic development of a country. His research findings highlighted the economic challenges faced by Zimbabwe and the need to look for entrepreneurship skills evident in the new curriculum. The study highlighted that though there are entrepreneurship skills inherent in the new curriculum, these needed to be emphasised. Saiden (2017) argues that the curriculum developers were not adequately prepared for the implementation of the curriculum as they lacked experience in entrepreneurship development. Furthermore, in the Zimbabwean context, it was suggested that curriculum development includes the areas of entrepreneurship previously omitted and that these be linked to components of STEM to spearhead economic development. Saiden's (2017) study reveals the fragmented nature of STEM and entrepreneurship in curriculum development, not only in Zimbabwe but in South Africa as well. It should be noted that the curriculum interpretation and implementation should not only go beyond the simple transfer of knowledge but also need to include the cultivation of creative, innovative thinking utilising the principles of mindful teaching and learning practices including executive functioning and emotional intelligence. Furthermore, emotional intelligence includes the exercising of engagement, compassion and motivation. The inclusion of these 'soft' skills supports the development towards a more nuanced understanding of the entrepreneurial skills and the appropriate application in educational and economic business environments.

In South Africa, Art and Design is offered separately from Engineering and related courses at TVET colleges, and Art and Design is offered at the Nated (N4 to N6) level. At the College of Cape Town, the course covers the fields of graphic design, photography or graphic processes. It consists of Nated N4, N5 and N6 certificates. After completing the N6 Certificate, students are required to gain a set number of hours of practical experience in industry before they can qualify for the National N-Diploma. Although this course along with others in the Nated suite of qualifications is under review, it does give the prospective student entry into the creative industry. Another area where students can practice artistic skills is in Computer Aided Design (CAD) which links their creative skills with technology (https://cct.edu.za/).

However, in the cases highlighted above, as in many programmes offered at both TVET and ACET colleges, the provision of courses and their associated curriculums, and by extension the training of lecturers continue to be fragmented into its requisite disciplines. Integrating these programmes with entrepreneurship and indigenous knowledge systems will require political will, resourcing and changes to lecturer training programmes.

Case study 4: Teacher education and the use of puppetry

At both the North-West University and the UWC, there is a strong focus on including STEAME approaches in both pre-service and in-service teacher education. One such example is the use of puppetry and drama as engaging pedagogies. Puppetry is a very effective pedagogy to address the affective domain in the STEM classroom (Brits, De Beer & Mabotja 2016; Dahlstrom 2014). Teachers need to also consider the affective domain that includes the five levels as outlined below:

- *Receiving*: It is the lowest level of being conscious of something. On this level, the learner passively pays attention to an object or state of affairs. The receiving level can be described as firstly an awareness, then a willingness to receive and then controlled or selected attention. Some action words describing outcomes at the receiving level are attend, listen, look, be aware and notice.
- *Responding*: The learner actively participates in the learning process; the learner not only attends to a stimulus but also reacts in some way. Objectives at the responding level require the learner to comply with given expectations by attending or reacting to certain stimuli. Some action words that describe outcomes at the responding level are comply, follow, practice, discuss and participate.
- *Valuing*: The learner attaches a value to an object, phenomenon or piece of information. In valuing, the learner is expected to demonstrate a preference or display a high degree of certainty. The action words linked to the valuing level are debate, display, express an opinion and argue.
- *Organising*: The learner can put together different values, information and ideas and accommodate them within his or her own schema, comparing, relating and elaborating on what has been learned. This level requires a commitment to a set of values. Learners are expected to organise their likes and preferences into a value system and then decide which are dominant. The action words linked to the organising level are, for instance, compare, formulate, decide on, define and select.
- *Characterising*: The learner holds a particular value or belief that now exerts influence on his or her behaviour so that it becomes a characteristic (Borich & Tombari 2004, pp. 49–50; Nitko 2004, p. 29463).

In the five categories of the affective domain, some subcategories seem to describe the affective reaction of the learner. These subcategories appear to describe the level at which a learner will respond or value a particular object in showing, for instance, an acceptance of a valued statement, a preference for such shows full commitment to an object or phenomenon.

Some learning targets that are attached to the categories in the affective domain describe fields of study or subjects, for instance, to develop an awareness of aesthetic factors in architecture (receiving level) or to find pleasure in reading for recreation (responding level).

Affective objectives typically target the awareness and growth in attitudes, emotion, interests, dispositions and feelings (Nitko 2004, p. 22). The effect of the affective domain on cognitive engagement and responses is of utmost importance. Lazarus (1991, pp. 19–22) describes this affective-cognitive relation as 'the marriage between emotion and thought'. The use of puppetry as pedagogy is in essence an application of Lazarus's cognitive-mediational theory which holds that cognitive activity may consciously or unconsciously take the form of conceptual processing of information (Lazarus 1991). This means that emotions (affect heuristics, feelings and gut-feeling reactions) are often used as shortcuts to process information and influence behaviour. This means that the valuing and organising levels of the affective domain related to information processing will be mostly affected by emotion (mood). The affective domain of valuing expects, for instance, of a learner to demonstrate a preference or display a high degree of certainty regarding an opinion. The affective domain of organising expects the learner to combine different values, information and ideas and accommodate these by comparing, relating and elaborating on what has been learned. This finding is in line with Joseph Forgas' (1995, pp. 43–58) explanation in the affect infusion model (AIM) of how emotion and mood interact with one's ability to process information. He argues that 'substantive processing', or systematic processing, involves the most elaborate cognitive processing and appears highest on the continuum as it is the most powerfully affected by mood. Emotion plays a significant role, especially in situations that require cognition about difficult, peripheral subjects. Instances that require judgement of obscure, atypical subjects also appear to be most affected by emotion (affective domain).

Through the use of puppetry as a teaching and learning strategy, it becomes possible that the learner experiences learning in a playful manner and does not feel threatened by content, information or a burdening task. This contributes to finding equilibrium and effective assimilation and accommodation of new information.

The question might then be that if the use of puppetry assists in finding affective-cognitive domain equilibrium, why is the general use of puppetry still limited?

Research shows that teachers initially show resistance to using puppetry as a pedagogy in the STEM classroom, and this often stems from their particular views of the tenets (nature) of science

(De Beer, Petersen & Brits 2018) and the main focus on cognition, content and information. Rotherham and Willingham (2010) showed that teachers often emphasise problem-solving and critical thinking when addressing 21st-century skills, marginalising attributes and skills such as values, respect, tolerance, ethical behaviour and academic honesty. The latter authors state that these important outcomes are often dealt with as:

> [*A*] matter of chance rather than the deliberate design of our school system […] we cannot afford a system where receiving a high-quality education is akin to a game of bingo. (p. 17)

Science teachers often only focus on tenets such as the empirical and inferential nature of the natural sciences, ignoring other tenets such as its creative nature, or that it is embedded in social and cultural practices (Cronje 2015; White, Bester & Sebotsa 2019). The utilisation of puppetry holds many affordances in STEAME education. Keogh et al. (2008) emphasise that puppetry creates learning opportunities that build on authentic problems, rooted in students' everyday experiences. Case studies showed that the customisation of activities where learners made their own commentaries, for example, helped to motivate students to engage and participate. Where learners execute learning activities that engender knowledge production and understanding and which are based on investigation, an increased self-directedness can occur (Stubbé & Theunissen 2008). Soord (2008) states the following about puppetry:

> Puppets are extraordinary. While they acquire a life of their own, they remain inanimate and can seem less intimidating when addressing sensitive issues. They break boundaries between people, both physically and emotionally. They allow us to take on numerous identities and act as a shield for us to hide behind. They can give people the confidence to say and do things they wouldn't usually say or do if they were visible. (p. iv)

Puppetry therefore could be an effective pedagogy when addressing sensitive issues in the STEAME classroom.

White et al. (2019) showed how an intervention utilising puppetry changed student teachers' views on puppetry. Before a puppetry intervention, a North-West University (NWU) student stated:

> Puppetry is not something that can be taken seriously by anyone above the age of 10 years, let alone high school students […] using puppets sounds quite insane to be honest. (p. 268)

However, student teachers' views changed, when exposed to puppetry pedagogy:

> It is fun and different, and a creative way to explain concepts. (p. 272)

> Puppetry brings a positive atmosphere in the class […] which leads to better participation by the learners. (p. 272)

All four examples given above are examples of the current practice of arts and indigenous knowledge. The inclusion of entrepreneurship, though, is applied to varying degrees at the institutions.

Application of arts, entrepreneurship and indigenous knowledge in Science, Technology, Engineering and Mathematics

Here are two vignettes of the ways in which an effective application of arts and STEAM for the most part appear to have been equally in play (Mejias et al. 2021, pp. 224–225).

Infectious: Stay away exhibition in Science Gallery Dublin (2009)

Science Gallery Dublin brought a 'mutually instrumentalised pedagogical STEAM approach' to its programming of events outside of the gallery space such as science shows and festivals. Anyone who takes part in Science Gallery Dublin's events, activities or exhibitions can do so through the 'lens of art and science' in ways that can be 'witty, clever, even subversives, but never traditional', according to the STEAM approach.

Erase Your Face (2019)[24]

In 2019, an interactive team partnered with MIT App Inventor to create *Erase Your Face*, which is an exploration into special recognition software becoming increasingly prevalent in physical and digital spaces.

Erase Your Face is playful and dead serious. To create it, young people first had to immerse themselves in concepts, debates and models related to artificial intelligence (AI), exploring how facial recognition works and problems with its deployment in diverse contexts ranging from law enforcement to concert arenas. The team then designed a web-based interactive that invites users to experiment with various ways to dodge facial recognition by dragging and drooping filters, accessories, fashion and make-up styles over a face of their choosing. Importantly, the young people imagined, designed and coded every aspect of their interaction (Mejias et al. 2021, p. 225).

These examples are inspiring and are offered in the hope that similar initiatives may become pedagogically possible for A & E in STEAME contexts more widely across the world. Infusing A & E will require a review

24. Parts of this section are based on the published material: Mejias et al. (2021, pp. 209–231).

of current preservice and in-service teacher/lecturer training. This will include a more collaborative and integrated approach to delivering the content by faculty.

Indigenous knowledge holds many affordances to better contextualise Western curriculum themes for culturally diverse learners (see Chapter 2). The nature of indigenous knowledge also provides opportunities to utilise arts approaches and develop entrepreneurial skills.

An example from the field of ethnobotany to demonstrate the potential of indigenous knowledge to develop an entrepreneurial mindset in science learners is *Elytropappus rhinocerotis* (the 'renosterbos'), a plant that commonly grows in the Northern Cape province in South Africa (see Figure 11.3).

This plant has traditionally been used to prevent foot odours. Traditionally, a twig of the Renosterbos was put in the shoe, to ensure that feet do not smell. Hulley et al. (2019) tested this plant and show that diterpenoids in the plant give it strong antimicrobial activity against *Brevibacteria* (responsible for foot odours) and that this plant is 200% more effective than commercial foot powders that are commercially available. This plant has not been explored much in terms of its economic/entrepreneurial opportunities. This is but one of many hundreds of South African plants that could have

Source: Ben-Erik van Wyk (n.d.) (n.p.). (Published with permission from the photographer.)

FIGURE 11.3: *Elytropappus rhinocerotis*, a plant that holds much economic potential for an entrepreneur to explore.

economic and entrepreneurial potential. However, this is also a minefield, in so far that we should guard against the exploitation of indigenous knowledge holders' knowledge. Working with holders of indigenous knowledge, and ensuring that they benefit from knowledge sharing, holds potential for job security and economic growth in South Africa. Such discussions in the STEM classroom also open up opportunities to discuss ethics when it comes to indigenous knowledge research. Andries Steenkamp, a respected San leader, once commented 'Come through the door not the window' (Speight Vaughn & Mdakane 2019, p. 319), highlighting the ethics of mutuality, respect and reciprocity when working with indigenous knowledge holders. Again, this emphasises how indigenous knowledge holds affordances to centre stage the affective domain in the STEM classroom.

Application of arts, entrepreneurship and indigenous knowledge in Science, Technology, Engineering and Mathematics: Challenges

The previous section highlighted some examples of arts, entrepreneurship and indigenous knowledge in the context of schools as well as ACET and TVET colleges. We have noted some of the comments from literature highlighting the importance of these three concepts in the South African education and training context. These include increased problem-solving as well as creative and critical thinking. The important link to entrepreneurial skills development as well as the connection to indigenous crafts plays a critical role in harnessing the economic and job creation potential of local communities. However, along with these opportunities, several challenges abound including the curriculum context and the socio-economic barriers. In this section, we will be highlighting three challenges that may impinge on the implementation and adoption of arts, entrepreneurship and indigenous knowledge in STEM subjects. These are the role of women in STEAME, the rural context and access to technology.

The role of women in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship

Literature has underscored the important role of women in STEM. Authors have argued that the lack of involvement of women has had a negative impact on institutions and communities, especially in the context of socio-economic development. Kuschel et al. (2020) stated that STEM is essential for innovation and technological development, which are viewed as catalysts of socio-economic growth. They argue that researchers and policy-makers have focused extensively on analysing and encouraging high-growth opportunities in the STEM fields. However, it was found that these STEM fields are highly gender-skewed, irrespective if the population sampled are students, faculty members, graduates, managers or entrepreneurs. Kushel et al. (2020) furthermore point out that the gender-skewed phenomenon is noticeable in women entrepreneurs who have STEM backgrounds. This underrepresentation of women in innovation-driven business ventures further highlights existing gender biases and systemic weakness in social structures. This in turn promotes the male dominance that occurs at the juncture of STEM and entrepreneurship. The authors emphasise the importance of institutional, organisational and individual components impacting on women's entrepreneurship in STEM fields.

Furthermore, Poggessi et al. (2020) argue that the literature on women in the STEM fields is still limited and fragmented. They do, however, highlight development opportunities that require political will, government support and research-led approaches to policy development and implementation.

Although there has been increasing government focus and subsequent funding on emphasising STEM subjects to female students, this needs to be sustained and enhanced, especially the importance of bridging the learning from the institution to the development of entrepreneurship.

■ The rural context

Although there has been increased focus on the rural development of STEM in rural schools and colleges, many challenges remain. Mtsi and Maphosa (2016) highlight the numerous challenges faced by rural teachers and learners including the lack of essential infrastructure and resources for science teaching. There were also difficulties related to learner background, the language of instruction and the lack of parental involvement.

However, additional challenges are evident, such as limited industry and job prospects, and limited disposable income resulting in little chance to grow a business beyond small business. The development of the agricultural and tourism industry along with infrastructure projects is very important for the development of communities.

■ Access to technology

The coronavirus disease 2019 (COVID-19) pandemic had an enormous impact on South Africa's education and training landscape (Mnguni & Mokiwa 2020). The post-pandemic reality had laid bare the digital divide between the rich and poor. Access to technology has been found to be vital to STEM subjects as well as the promotion of A & E on online platforms such as Facebook, TikTok and Instagram.

At a 2022 STEM conference, keynote speaker Dr D Fish emphasised the importance that all learners in South Africa have access to good science and mathematics teaching. He noted that the COVID-19 pandemic allowed a break in the digital divide and made learning more accessible to rural communities. He, however, stated that not all children have the same opportunities in STEM education and that innovative ways had to be found to address these challenges.

In looking at possible solutions, Fish (2022) argued that if learning is done using ‘offline’ digital materials, all learners can have access to these resources. The use of this kind of innovative and cost-effective technologies can bring education to everyone. Examples of these digital learning materials were compiled by the UniZulu Science Centre, saved on a USB flash drive and distributed to schools. This type of interactive materials can be used in a way that will assist teachers to incorporate the materials into their teaching. This method is representative of several initiatives by institutions and NGOs aimed at addressing the lack of access to the internet or technology, especially in poor and under-resourced communities.

Although challenges exist with regard to gender, the rural environment and access to technology, creative solutions will allow these to be addressed.

Conclusion

In this chapter, we have attempted to capture vignettes of how to infuse A & E in the STEM disciplines. What we have found was that although there are examples of the practice of A & E, infusing these in STEM has not happened effectively to the extent it should. Part of the problem is the views that STEM teachers often hold of the nature of the discipline (i.e. empirical and inferential, often dismissing the social, cultural and creative tenets of science). Both pre- and in-service teacher education should focus more on providing STEM teachers with a more nuanced understanding of the nature of the STEM field. In order for A & E to find its place in the STEAME context, it needs to be sustained through a number of processes. This includes not only curricular considerations, funding and resourcing of schools and colleges but also teacher/lecturer training and development.

Watson et al. (2013) argue that:

> STEAM doesn’t merely add art to STEM, it changes STEM’s focus from better test scores in the core STEM academic disciplines to better quality of inclusive thinking and from focus on the development of a larger, technically competent workforce to one that is also more innovative. (p. 5)

Chapter 12

Emerging information communication technologies in STEAME education

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Abstract

This chapter navigates the evolving landscape of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education, examining the transformative integration of emerging information and communication technologies (ICTs). It focuses on fostering self-directed learning (SDL), problem-based learning (PBL), cooperative learning and the concept of gamification, particularly engaging learners as *Homo ludens*, the playing human.

Identifying four technological pillars, namely, artificial intelligence (AI), virtual reality/augmented reality (VR/AR), internet of things (IoT) and gamification for enriching educational dimensions, our integrated lens,

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grounded in the community of inquiry (COI) framework and critical realism, informs an emergent analytical framework. The COI framework provides a systematic guide to leverage these technologies strategically.

We distil key insights, emphasising the transformative potential of emerging technologies and the collaborative efforts needed to bridge educational gaps. Common themes and challenges are identified, framed by theoretical lenses, contributing to the scholarly discourse. Actionable guidelines are proposed for navigating challenges and opportunities in the dynamic world of STEAME education, making it relevant to educators, policymakers and stakeholders. Future directions suggest areas for research, advocating for STEAME education's continuous evolution in the face of technological advancements. This exploration unfolds as a holistic convergence of technology, pedagogy and knowledge – shaping a dynamic, inclusive educational landscape for future generations.

■ Introduction

As the landscape of education undergoes constant change, the integration of emerging information and communication technologies (ICTs) emerges as a powerful force reshaping learning experiences, particularly within the domains of Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship (STEAME) education disciplines (Barakabitze et al. 2019, pp 18–22). This chapter embarks on a comprehensive exploration of the transformative possibilities embedded in these technologies, focusing on their application to enhance self-directed learning (SDL), problem-based learning (PBL), cooperative learning and the captivating concept of gamification. At the core of this exploration lies the fundamental concept of engaging learners as *Homo ludens*, the playing human (Huizinga 1950), in the learning process.

The transformative landscape prompts a fundamental question: How can the dynamic interplay of emerging technologies be strategically leveraged to foster SDL, PBL, cooperative learning and gamification, contributing to designing a future-proof and transformative educational landscape for all learners in school and university settings?

■ Enhancing Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education through self-directed learning and emerging information and communication technologies

In an era of rapid technological advancements, shifting societal landscapes and evolving workplace demands, the traditional education paradigms are undergoing a profound transformation. Self-directed learning stands at the forefront of this educational revolution, a pedagogical approach that empowers learners to take charge of their educational journey and cultivate the skills essential for the future (Morris 2019, p. 12). Self-directed learning is not merely a process, it is a philosophy that places the learner at the centre of their education, fostering a proactive and inquisitive mindset. At its core, SDL is a process where individuals navigate their learning path, set goals and actively seek resources and experiences to achieve those objectives.

Central to the philosophy of SDL is the cultivation of student autonomy. Student autonomy refers to the capacity of learners to take charge of their educational journey actively (Bouchard 2012). In the context of SDL, autonomy implies that students are free to make decisions regarding what, how, when and where they learn, allowing them to exercise control over their educational experiences.

In highlighting the importance of fostering student autonomy in SDL, Du Toit-Brits (2019) underscores the significance of educators' positive expectations, creating an SDL-friendly environment, and active involvement in SDL practices. Educators' attitudes, enthusiasm and commitment shape a positive learning culture, encouraging students to embrace SDL. Conversely, negative expectations can impede students' autonomy and motivation in the SDL process. Educators play a pivotal role in shaping students' self-directedness through their beliefs, actions and the learning environments they create.

In addressing the imperative to enhance SDL in primary and secondary education, it is crucial to recognise pervasive challenges, such as limited social presence, as identified by Niess and Gillow-Wiles (2021). Their research underscores the evolving role of teachers in the context of advanced digital technologies, offering critical insights for effective SDL implementation. By strategically incorporating educational technologies, educators can respond to these challenges, employing innovative instructional strategies that foster meaningful student engagement and collaboration while adeptly navigating the constraints associated with virtual instruction. This approach involves carefully selecting and implementing technologies aligned with the overarching goal of promoting SDL.

In tandem with SDL, personalised learning emerges as a natural extension, enriching the educational experience by tailoring it to each learner's needs, preferences and progress. Personalised learning environments leverage emerging technologies, such as adaptive learning systems, artificial intelligence (AI) and data analytics, to create adaptive, student-centric landscapes (Lampropoulos et al. 2022). This interconnected approach, highlighted by Malaise and Signer (2022) and Lampropoulos et al. (2022) underscores the dynamic evolution of education towards a more adaptive, student-centric and technology-enhanced landscape.

Building on the expertise reversal effect introduced by Kalyuga et al. (2003) demonstrated the critical need for tailored instructional design based on learners' expertise levels through empirical evidence. The shift from detailed work examples beneficial for novices to problem-solving activities preferred by more experienced learners highlights the dynamic nature of practical guidance in education. This concept finds further support in the work of Malaise and Signer (2023), who applied the expertise reversal principle to advocate for personalised learning within learning and code exploration. Their emphasis on adaptive instructional design reinforces the idea that the level of support provided to learners should be contingent on their expertise, reflecting individual learners' evolving needs and competencies.

Advocating for a peel-away design, Malaise and Signer proposed an approach allowing the learning environment to dynamically adjust the amount of support based on the learner's proficiency. They also extended the idea of personalised learning to content selection, aligning with Vygotsky's (1978) zone of proximal development and ensuring that tasks fall within an optimal learning zone, avoiding extremes of being too easy or too difficult.

As we explore the broader context of personalised learning environments, the focus shifts to tailoring educational experiences to individual student needs – a departure from the conventional one-size-fits-all approach. Traditional educational settings, characterised by fixed curricula, uniform pacing and limited flexibility, contrast personalised learning principles. This approach acknowledges students' strengths, weaknesses and interests, fostering critical thinking, problem-solving skills and a genuine passion for lifelong learning.

In the context of personalised learning, the philosophy of SDL seamlessly aligns, as both emphasise placing the learner at the forefront, encouraging autonomy, and adapting educational experiences to individual needs and preferences. This philosophy is a powerful means to empower students to take control of their educational journey, merging the principles of SDL with the transformative potential of emerging technologies.

Integration of information and communication technologies in education: Promises and challenges

In pursuing enhancing SDL through integrating emerging technologies, students gain the tools and opportunities to chart personalised learning paths, engage in global collaboration and cultivate an independent and inquisitive approach to knowledge acquisition. This departure from traditional instructional methods positions learners at the forefront of their educational journey, fostering academic success and preparing them for a rapidly changing world (Mahlaba 2020). Collaborative projects with peers worldwide allow for sharing of diverse perspectives and problem-solving approaches, aligning seamlessly with the interdisciplinary nature of STEAME subjects.

The intentional design of educational environments connects to the journey towards SDL. Blended learning, which combines traditional face-to-face instruction and online learning, offers a flexible and dynamic platform for learners to personalise their learning paths, collaborate with peers worldwide and develop an intrinsic drive for knowledge acquisition.

Insights from Wittmann and Olivier's (2021) study on blended learning in teacher professional development programmes contribute valuable considerations for enhancing STEAME education. These insights emphasise the need for teachers to acquire skills in effectively integrating ICTs, designing and engaging blended learning experiences, and accommodating diverse student needs.

However, it is also important to recognise that the integration of ICT in education presents certain challenges. For instance, Witmman and Olivier (2021), Gyamfi (2005) and Barakabitze et al. (2019) also highlight several challenges such as (1) the struggle to design learning environments that accommodate the varying levels of digital literacy among the learners; (2) the scarcity of technical support making the seamless integration of ICTs difficult; (3) digital inequality in many regions; (4) disparities in access to digital tools and internet connectivity; (5) the digital divide restricts equitable learning opportunities; and (6) infrastructural and resource limitations, resistance/distrust from teachers because of unfamiliarity.

The dynamic interplay between pedagogical strategies, cultural factors and the unique needs of participants in a blended learning environment finds application in STEAME subjects through personalised learning paths, interactive digital resources, hands-on experiences and cultural considerations that enrich the learning experience. Furthermore, Wittmann and Olivier (2021) advocate adopting PBL practices to augment SDL, aligning seamlessly with the inherent problem-solving nature of numerous STEAME disciplines. The study underscores the importance of arts in making content more engaging and relatable for students from diverse backgrounds (refer to Chapter 2).

Future-proofing education: Blending technologies, critical realism and pedagogical wisdom

The integration of ICT has laid a robust foundation, with promises to reshape learning environments, optimise outcomes and ensure equitable access to knowledge. Critical realism, as advocated by Bhaskar (1978, 1979, 2002), delves into the underlying structures and mechanisms influencing observable phenomena. Critical realism acknowledges a deeper layer of reality independently of our perceptions, unlike positivism and interpretivism. In educational inquiry, critical realism provides a robust framework for navigating the complexities of educational technology, recognising both observable patterns and deeper, often hidden, mechanisms that influence learning environments (Li 2013). This application ensures a holistic understanding beyond surface-level observations, emphasising the ongoing and emotionally charged nature of students' educational journeys. Learners' decisions, influenced by reflections and emotions, become pivotal in shaping the success of e-learning initiatives, aligning with Bhaskar's critical realist perspective. As students navigate their educational journeys, their identities undergo continuous revision. Viewing learning technology as embedded in real-world contexts, learners make choices guided by a deeper understanding of how these technologies fit into their practical realities, not solely relying on surface-level functionalities. Achieng's (2022) critical realist evaluation of digital technology in South African higher education enhances teaching and learning activities by recognising generative mechanisms, such as technology aesthetics and self-efficacy.

Critical realism, introduced as a philosophical lens, encourages exploration beyond surface-level observations into the intricate dynamics often present. This philosophical framework connects the transformative potential of emerging technologies and blended learning with the nuanced exploration of underlying educational structures, providing a robust foundation for navigating the complexities of educational technology. By acknowledging the importance of observable patterns and underlying structures in educational experiences (Li 2013), educators can balance relying on empirical evidence and cultivating a deeper understanding of the realities shaping educational experiences (Li 2013).

■ Formation of analytical constructs and theoretical frameworks

The philosophical foundation of critical realism aligns seamlessly with the future-proofing strategies essential for enhancing STEAME education through emerging technologies. Critical realism acknowledges observable patterns and underlying structures in educational experiences, providing a comprehensive framework for navigating the transformative landscape of technology integration.

Similarly, the community of inquiry (COI) framework, developed by Garrison, Anderson and Archer (2000), provides a well-established theoretical foundation for understanding and enhancing the educational experience, particularly in online and technology-enhanced settings. Community of inquiry identifies three essential elements, namely, cognitive presence, social presence and teaching presence. Cognitive presence refers to a learner's ability to construct and affirm meaning through reflection and discourse (Garrison, Anderson & Archer 2001). According to Garrison and Anderson (2003, p. 29), critical thinking is essential to the learning process as it enables learners to develop higher-order knowledge within the learning context. Social presence is the capacity to present one's identity within the online community, establishing a perception of being an authentic person (Garrison et al. 2000). It holds significance as it serves as a supportive element for cognitive presence (Garrison et al. 2000). This indirect support facilitates the critical thinking process undertaken by the community of learners. It directly contributes to the overall success of the educational experience (Garrison et al. 2000, p. 89). Teaching presence is defined as the planning, facilitation and guidance of cognitive and social processes to achieve personally meaningful and educationally valuable learning outcomes (Anderson, Krathwohl, Airiasian, Cruikshank, Mayer, Pintrich, Raths & Witt Rock 2001, p. 5). Teaching presence harmoniously integrates the other two forms of presence in a well-balanced and functional relationship (Garrison & Anderson 2003). This alignment is consistent with the intended educational outcomes and is responsive to the needs and capabilities of the learners. By incorporating these elements, our analytical framework ensures a holistic consideration of cognitive engagement, social interaction and instructional design within emerging technologies.

The formulation of our integrated lens, recognising the interconnected facets of SDL, PBL, cooperative learning and gamification, aligns with the social and cognitive presence components of the COI framework. This integration fosters a collaborative and intellectually engaging environment where learners construct knowledge through meaningful interactions. Critical realism principles further enrich our analytical lens, allowing us to delve deeper into the structures influencing the educational ecosystem and complementing the COI framework. By adopting this lens, we acknowledge the dynamic and evolving nature of the educational landscape and aim to reveal the generative mechanisms contributing to the success or challenges in leveraging technology for educational transformation.

■ Technological pillars: Enhancing educational dimensions

To strategically leverage emerging technologies in STEAME education, we identify key technological pillars shaping the landscape. While acknowledging the continual evolution of the technological terrain, we spotlight four pillars (Table 12.1) that play a pivotal role in our integrated lens and emergent analytical framework.

TABLE 12.1: Technological pillars shaping the landscape.

SDL	PBL	Cooperative learning	Gamification
Technological pillar 1: Artificial intelligence (AI)			
AI catalyses personalised learning experiences, adapting content and pace to individual student needs (Malaise & Signer 2023; Triplett 2023)	Real-time feedback from AI systems fosters continuous improvement and understanding, enriching the problem-solving process (Triplett 2023)	AI contributes to adaptive learning systems, supporting collaborative problem-solving and group dynamics (Botha-Ravyse, Lennox & Jordaan 2018; Liston, Morrin, Furlong & Griffin 2022; Triplett 2023)	AI's integration enhances gamified systems (e.g. Duolingo), offering intelligent adaptability and personalised challenges. (Botha- Ravyse et al. 2018; Palaniappan & Noor 2022; Liston et al. 2022; Triplett 2023)
Technological pillar 2: Virtual/augmented reality (VR/AR)			
VR/AR creates immersive environments for self-directed exploration of complex concepts (Tene, Marcatoma Tixi, Palacios Robalino, Mendoza Salazar, Vacacela Gomez, & Bellucci 2024)	Realistic simulations offered by VR/AR enhance hands-on experiences in problem-solving (Learnomics Media 2024)	Gamified elements within VR/AR foster engagement in group activities (Lampropoulos et al. 2022)	VR/AR introduces interactive narratives, rewards and challenges, enhancing gamification strategies (e.g. Google expeditions, or ClassVR) (Botha- Ravyse et al. 2018; Lampropoulos et al. 2022; Liston et al. 2022; Ribeiro, Santos, Lobo, Araújo, Magalhães, & Adão 2024)
Technological pillar 3: Internet of things (IoT)			
IoT creates smart learning environments with real-time monitoring and adaptive learning systems (Kuppusamy 2019; Triplett 2023)	IoT transforms traditional activities, providing diverse opportunities for problem-based exploration (Kuppusamy 2019)	IoT fosters collaboration through interconnected devices and smart learning environments (Kuppusamy 2019)	IoT-based systems introduce game-like elements, enhancing motivation and engagement (Botha-Ravyse et al. 2018; Liston et al. 2022)
Technological pillar 4: Gamification			
Gamification promotes autonomy, active participation, and personalised learning experiences (De Troyer, Maushagen, Lindberg, Muls, Signer & Lombaerts 2019)	Gamified systems introduce challenges, rewards and interactive narratives, fostering problem-based exploration (Lampropoulos et al. 2022)	Gamification enhances group dynamics and collaboration in cooperative learning settings (De Troyer et al. 2019)	Gamification: Ongoing studies showcase the positive impact of gamification on academic performance and SDL (De Troyer et al. 2019; Liston et al. 2022; Palaniappan & Noor 2022; Botha-Ravyse et al. 2018)

Source: Authors' own work.
Key: SDL, self-directed learning; PBL, problem-based learning; AI, artificial intelligence; VR, virtual reality; AR, artificial reality; IoT, internet of things.

While these pillars are foundational, it is essential to note the dynamic nature of the technological landscape. Later in this chapter, we will explore broader technological trends, ensuring a comprehensive understanding of their implications for STEAME education. The synergy among various technologies, including emerging ones such as blockchain and data analytics, will also be explored, recognising their varying prevalence based on institutional priorities and educational objectives. This adaptive approach contributes to shaping a holistic STEAME education experience.

Operationalising the integrated lens

The operationalisation of our integrated lens involves the strategic alignment of COI's cognitive, social and teaching presence with critical realism's emphasis on underlying structures. By treating SDL, PBL, cooperative learning and gamification as interconnected facets, we aim to capture the richness of the educational experience within the COI framework. Simultaneously, the critical realism lens prompts educators to go beyond the immediate observable effects of technology, encouraging a nuanced understanding of the generative mechanisms at play. Through the fusion of these frameworks, our analytical constructs provide a comprehensive and nuanced exploration of how emerging technologies contribute synergistically to the varied dimensions of STEAME education. This approach ensures that educators recognise the observable impacts of technology integration and comprehend the deeper structures shaping the transformative potential in educational settings. Thus, our analytical constructs and theoretical frameworks, rooted in the COI framework and enriched by critical realism, offer a holistic and depth-oriented perspective on integrating emerging technologies in STEAME education.

Emergent analytical framework

While related, the integrated lens and emergent analytical framework serve distinct purposes. The integrated lens above provides a holistic perspective on exploring emerging technologies within STEAME education, emphasising the interconnectedness of SDL, PBL, cooperative learning and gamification. It guides our understanding of how these facets form a cohesive and comprehensive educational experience. On the other hand, the emergent analytical framework is a structured and strategic approach to leveraging emerging technologies.

Advancements in emerging technologies

This section serves as a gateway into the dynamic realm of emerging technologies within STEAME education. By drawing on the insights derived from a critical realist perspective, we transcend surface-level observations to probe into the profound impact of these technologies on the educational landscape. As previously mentioned, our exploration extends beyond the superficial, unravelling the realities and transforming emerging technologies into powerful tools for enriching educational experiences.

As we navigate this section, we will focus on a detailed examination of specific technological pillars. These pillars, including AI, VR, the IoT and gamification, are integral components shaping the future of STEAME education. Each pillar will be scrutinised through the emergent analytical framework (discussed above), providing a holistic perspective on its applications, benefits and potential challenges as we embark on this journey to discover how these advancements not only influence educational methodologies but also redefine the very essence of teaching and learning in the STEAME domain.

Integrating IoT into STEAME education promises to create connected and smart learning environments (Liston et al. 2022; Palanivel 2019). In the context of Rosmansyah et al. (2023), a smart learning environment is a hybrid learning system that fosters a pleasant learning experience for learners and stakeholders. It simultaneously achieves learning outcomes through intelligent tools and techniques. A noteworthy example supporting this argument is the STEAM-ED project presented by Liston et al. (2022), emphasising a transdisciplinary approach to STEAM education. The project involves designing and implementing STEAM education delivered to pre-service and in-service teachers, addressing critical challenges faced in delivering STEAM at the elementary level. The STEAM-ED project incorporates an IoT-based environment monitoring system, showcasing how physical and digital technologies, especially IoT devices, can revolutionise teaching and learning practices in elementary classrooms.

Sensor technologies and IoT transformed the traditional weather station, providing diverse STEAM teaching and learning opportunities. The IoT-based system supports activities involving communication, collaboration, critical thinking and creativity, recognised as essential skills for 21st-century learners (Thornhill-Miller et al. 2023, p. 2). This interconnected approach fosters a dynamic and responsive educational landscape, aligning with broader goals of creating context-aware activities for learners (Liston et al. 2022). This project exemplifies the potential of IoT in education by offering real-time monitoring with smart sensors and adaptive learning systems for personalised experiences (Palanivel 2019). Internet of things contributes to hands-on learning experiences and interoperability between standards, further enhancing the potential of IoT in education (Palanivel 2019; Todorov & Vela 2023). Additionally, the transdisciplinary nature of the project addresses the accessibility of IoT in STEAME education, providing a more customised learning experience for students, including those with disabilities (Kent, Ellis & McRae n.d.), in line with the inclusive goals of education (Department of Education 2001). Therefore, the STEAM-ED project is a compelling illustration of the transformative impact of IoT in creating connected, adaptive and inclusive learning environments.

While incorporating IoT in education offers numerous benefits, Saadé's et al. (2023) study sheds light on the current landscape of educators' knowledge and utilisation of IoT, pointing out that educators, especially in non-technical disciplines, may have limited exposure to IoT tools. This aligns with the broader discussion on the challenges associated with IoT in education, including high installation expenses, the absence of universal, circumstance-aware learning environments, resistance from teachers to modern technologies, and the need to reconsider current teaching approaches (Saadé et al. 2023), challenges related to device compatibility and privacy limitations (Dilmegani 2023) and security (Abiodun et al. 2021; Dilmegani 2023). These challenges underscore the importance of strategic planning and comprehensive approaches to ensure IoT's effective and secure implementation in STEAME education. Ajigini (2023) supports these points by highlighting that performance expectancy, social influence and effort expectancy positively influence behavioural intention to adopt IoT, with effort expectancy having the strongest impact, while facilitating conditions do not have a significant effect. Saadé et al. (2023, p. 459) propose an internet of intelligence of things in education (IoITE) conceptual model, building on the concept of artificial intelligence of things (AIoT) as a novel paradigm that proposes the use of intelligence in the various layers of the IoT as an integral architectural component of an educational institution's global ecosystems. The conceptual model can be used to develop institutions' digital strategies to assess the extent of their capabilities to use IoIT in their learning processes. Artificial intelligence of things refers to integrating AI technologies with the IoT, combining AI's power, enabling machines to simulate human intelligence, with IoT, connecting everyday devices to the internet (Sung, Tsai, Gaber & Lee 2021, p. 1). Internet of things's transformative approach aligns with the broader goals of creating adaptive, inclusive and technologically enriched educational landscapes.

Acknowledging that IoT STEAME education creates connected and smart learning environments, our exploration now shifts to gamification.

As a powerful educational strategy and building on connected learning environments, gamification offers unique affordances that enhance student engagement and foster autonomous learning experiences. Gamification promotes autonomy and active participation by introducing game elements, such as challenges, rewards and interactive narratives, into educational contexts (De Troyer et al. 2019; Ratinho & Martins 2023). This approach can significantly contribute to reshaping the learning landscape within emerging technologies.

In SDL's realm, the integration of gamification plays a pivotal role in transforming the educational experience. Examining the affordances of gamification reveals its potential to enhance student motivation, foster a sense of autonomy and create a dynamic and engaging learning environment. In this context, TICKLE's mobile digital environment is a notable example. TICKLE is a playful digital environment that allows youngsters to collect digital cards by performing associated challenges in their surroundings. TICKLE's design, infused with persuasive principles and gamification strategies, aligns seamlessly with the principles of SDL, emphasising autonomy and engagement. Developed to tackle school burnout and prevent early-school leave (ESL), TICKLE uses small, engaging activities to reactivate students interest in learning. By incorporating micro-learning, persuasion and gamification, it aims to re-engage students and foster a sense of accomplishment through incremental challenges (De Troyer et. al 2019). The playful environment and micro-learning approach in TICKLE resonate with the concept of engaging learners as *Homo ludens*, fostering a more personalised and engaging educational journey within emerging technologies.

Delving into the transformative effects of gamification on learners' academic performance and their levels of SDL within the realm of online education, a study conducted over a five-week duration involved 29 second-year undergraduate students engaged in a foundational programming language course. The gamification elements incorporated elements such as competition to accrue points, leaderboard rankings and the attainment of a Python programmer badge. The study's findings showcase a noteworthy enhancement in learners' academic performance after the integration of gamification. Furthermore, there was a substantial elevation in the participants' SDL levels, signifying a significant shift before and after implementing the gamification strategy. The gamification components, including points, ranks and badges, emerged as effective motivational drivers, fostering heightened engagement and commitment among learners throughout the learning process (Palaniappan & Noor 2022).

Within their study, Botha-Ravyse et al. (2018) enrich this discourse with valuable insights by exploring the practical implementation of gamification principles within a residential university setting in South Africa. Focused on students pursuing degrees and diplomas in Sport and Recreation Management, the investigation centres on a learning activity that employs a gamification approach, utilising a mobile app to prepare students for summative assessments. Highlighting the positive influence of gamification strategies on academic achievements and the development of crucial SDL skills, the study's findings offer a nuanced understanding of the intricacies of gamification and its impact on SDL, contributing practical wisdom to the earlier theoretical foundations. The emphasis on context-specific approaches underscores the importance of tailoring gamification to unique educational landscapes. Moreover, the study of Botha-Ravyse et al. (2018) reinforces the idea that well-designed gamification can catalyse motivation, active participation and a profound sense of accomplishment among learners.

Despite the widely acknowledged positive benefits of gamification in enhancing SDL, as highlighted in various studies, Mutekwe (2022) presents a contrasting narrative, revealing a limited adoption of gamified learning activities among classroom practitioners in South Africa, with only 5% of respondents incorporating gamification in their teaching practices. The reluctance of 70% of educators to adopt gamified teaching and learning despite learners' demands contributes to the limited integration. Additionally, a notable 20% expressed a desire to adopt gamification but cited constraints in expertise. The presence of resistance from traditional practitioners, who perceive gamified approaches as lacking elements for effective classroom practice, further hinders widespread adoption. Moreover, school policies, teacher attitudes and material constraints contribute to the challenging landscape, emphasising the need for comprehensive strategies to address these barriers and promote the effective use of gamified strategies in education. Mutekwe's work highlights significant challenges to adopting gamification in education, starkly contrasting the widely acknowledged positive benefits of gamified learning. The limited integration of gamification in teaching practices, as reported by only 5% of respondents, is attributed to various factors, including educator reluctance, constraints in expertise, resistance from traditional practitioners, and broader issues such as school policies and material constraints. By proactively addressing these aspects, educators can work towards overcoming the challenges identified by Mutekwe, fostering a more conducive environment for adopting gamification in education. This approach could lead to more widespread and effective implementation of gamified learning activities, enhancing classroom SDL. Amid these challenges, the gamification landscape in education unfolds, revealing a complex interplay of resistance, constraints and the undeniable potential for transformative impact.

The comprehensive study of Lampropoulos, Keramopoulos, Diamantaras and Evangelidis (2022) sheds light on the impactful combination of gamification and AR as we delve deeper into the transformative effects of emerging technologies in education; their study emphasises the positive outcomes, including increased engagement, motivation and active participation among learners. Recently, studies have shown similar effectiveness of VR in improving students' motivation, comprehension and retention of complex concepts (Grewe & Gie 2023; Kazu & Kuvvetli 2023). Additionally, Brij and Belhadaoui's (2021) research accentuates the multifaceted advantages of immersive technologies, underscoring how educational artefacts designed in VR and AR can significantly improve attention and cognition.

Furthermore, VR, an immersive and interactive technology, can be valuable for engaging students in diverse STEAME subjects and providing immersive, real-world experiences (Grewe & Gie 2023; Kazu & Kuvvetli 2023). Conducting a systematic literature review between 2013 and 2023, Kazu and Kuvvetli (2023) emphasise the value of VR in engaging students, contributing significantly to the educational experience. Specifically, students exposed to VR experiences demonstrated increased motivation, improved comprehension of complex STEAME concepts and enhanced retention compared to traditional teaching methods. Grewe and Gie's (2023) study supports these findings, highlighting instances where VR facilitated real-world simulations, allowing students to apply theoretical knowledge practically.

This customisation extends to the effective integration of VR in education, where careful consideration of design and medium is essential to ensure that the technology aligns with educational objectives, as emphasised by Veermans and Jaakkola (2021), who stress the pivotal role of design in the success of VR in education and the importance of a balanced approach between enjoyment and educational outcomes.

However, challenges such as technical issues, the need for specialised training, occasional discomfort during prolonged use, cyber threats, psychological trauma and behavioural changes accompany the integration of VR in education (Kazu & Kuvvetli 2023; Kenwright 2018). These complexities necessitate careful strategic planning to ensure VR's effective and responsible use; thus, customising instructional methods and employing a suitable medium tailored to the specific area of knowledge is crucial (Moreno 2006). Acknowledging these challenges is crucial and requires careful strategic planning to ensure VR's effective and responsible use; thus, customising instructional methods and employing a suitable medium tailored to the specific area of knowledge are essential.

Drawing parallels with conclusions by Lampropoulos et al. (2022), considering students' unique characteristics, interests and personality traits, is paramount in successfully integrating gamification and VR into educational strategies. In our ongoing exploration, we will continue to unravel the multifaceted landscape of emerging technologies, moving from gamification to VR while acknowledging the potential benefits, complexities and challenges accompanying VR's integration into educational methodologies.

The existing research provides specific recommendations for effective VR use, advocating for pedagogically sound designs that transition from structured to less structured support (Grewe & Gie 2023; Veermans & Jaakkola 2021). It underscores the importance of age-appropriate concreteness in VR elements, suggesting a blended approach that combines virtual and natural elements for enhanced learning. By integrating these insights, we strengthen the argument for VR, acknowledging both benefits and potential drawbacks in educational settings and addressing challenges inherent in immersive technologies.

Mixed reality (MR) combines the strengths of VR and AR by creating an immersive and interactive user experience (Mohd, Shahbodin & Sedek 2023). Expanding our exploration into MR, Penn and Ramnarain (2023) conducted a systematic review of MR pedagogy in K-12 education, analysing 18 peer-reviewed journal articles from 2011 to September 2021. The findings reveal a predominant use of interactive learner-centred pedagogies, such as inquiry-based, activity-based, discovery and collaborative learning, in MR interventions. The insights from Penn and Ramnarain (2023) align with the discussions by Mohd et al. (2023), emphasising the creation of immersive and interactive environments that are particularly beneficial for fields such as medicine, engineering and aviation. Additionally, Suryodiningrat et al. (2023) also underscore the transformative potential of MR systems in experiential learning, improved outcomes, risk-free experiments, and skills development, with a specific focus on vocational education. Penn and Ramnarain's (2023) emphasis on learner-centred pedagogies further resonates with Suryodiningrat et al.'s (2023) focus on experiential learning, improved outcomes and skills development.

The proposition of a guiding framework by Penn and Ramnarain (2023) adds depth to the understanding of pedagogical processes in integrating MR technologies, reinforcing the need to explicitly consider pedagogical dimensions in MR-enhanced learning interventions. The synthesis of insights from Mohd et al. (2023), Suryodiningrat et al. (2023), and Penn and Ramnarain (2023) underscores the multifaceted benefits of MR in reshaping education, emphasising the importance of learner-centred pedagogies and providing a foundation for future research and practical implementation in both general and vocational education settings. Utilising MR in educational settings poses unique challenges, such as managing software tools during remote teaching and ensuring effective communication between teachers and students. Technical support and experienced students' involvement are vital strategies to address these challenges and can ensure a smoother integration of MR into educational practices.

Having explored the immersive experiences of MR, our journey continues into the synergistic realm, where MR seamlessly converges with AI in collaborative learning platforms. This section delves into how AI enhances interactive and group-based problem-solving, fostering a sense of community among learners. From integrating natural language processing (NLP) and computer vision to exploring advanced language processing capabilities that extend into emerging technologies like AR, we uncover innovative possibilities. This integration transforms traditional education and lays the groundwork for developing immersive and intelligent educational environments. The subsequent sections further unravel the multifaceted landscape of AI's transformative impact, including its role in advancing Science, Technology, Engineering and Mathematics (STEM) education, personalised learning experiences, and the intricate interplay with data analytics.

As we uncover the intersection of MR and AI in collaborative learning platforms, our exploration seamlessly extends to the broader landscape of emerging technologies. Revisiting the broader context of AI, AR, data analytics, collaborative learning platforms, and adaptive learning systems, we recognise the centrality of personalised learning experiences within this dynamic landscape (Lampropoulos et al. 2022; Malaise & Signer 2023). The student-centric approach advocated by Malaise and Signer aligns perfectly with our exploration of collaborative learning enhanced by AI technologies.

Lampropoulos et al. (2022) contribute significantly by introducing student modelling techniques, including knowledge graph creation, providing educators with comprehensive tools to assess student performance, identify challenging topics and understand underlying causes. This holistic integration enriches the discussion on the transformative impact of data analytics, reinforcing the interconnected nature of emerging technologies. Similarly, Qushem et al. (2003) explore the transformative possibility of data analytics in predicting academic performance for students majoring in computer science by employing predictive analytics and utilising machine learning algorithms; they develop an early warning prediction model based on performance data. The study demonstrates that accurate prediction of students' early-stage performance is possible with high accuracy, reaching 88% when considering only second-year course grades and 96% when incorporating all course grades. The transformative aspect lies in the shift from a traditional approach of reactively addressing poor performance to an emphasis on proactively improving the quality of educational processes. The predictive analytics model offers insights into identifying low-, medium- and high-performing students, enabling educators to take early corrective actions.

Continuing our journey through the evolving educational landscape, we navigate the intricate web of technologies reshaping the learning experience. The potential of AI to generate personalised recommendations and curate learning experiences that resonate with individual preferences and capabilities (Huang et al. 2020) speaks to the profound impact of data analytics on customising learning paths and not only tracking progress. Similarly, the effects of AI-enabled personalised recommendations in a flipped classroom show how tailored strategies contribute to heightened learning engagement, motivation and improved outcomes (Huang, Lu and Yang 2023). Personalised learning experiences take centre stage, offering tailored content and challenges based on individual student progress and preferences (Lampropoulos et al. 2022; Malaise & Signer 2023). Triplett's (2023) empirical insights into AI's role in STEM education further distinguish the transformative potential of AI in enhancing personalised learning, advanced analytics and instructional automation.

Our exploration into the transformative potential of emerging technologies extends to the innovative intersection of AI and AR. Collaborative learning platforms enriched with AI bring interactive and group-based problem-solving to the forefront, fostering a sense of community among learners. Integrating NLP and computer vision into AI introduces groundbreaking possibilities, including language learning support and enhanced visual content interpretation (Frąckiewicz 2023). The convergence of AR and NLP presents exciting prospects for immersive and intelligent educational environments. Educational AR applications, infused with NLP, can now understand and respond to user queries in real time, providing contextually relevant information. This blend of NLP and AR holds significant promise in creating personalised and engaging learning experiences that cater to individual learning styles and preferences (Lampropoulos 2023). Augmented reality and voice recognition in English language learning further accentuate the ongoing advancements in technology-enhanced learning (Zain 2023; Marrahi-Gomez & Belda-Medina 2024).

Contributing significantly to understanding the role of AI in STEM, Triplett (2023) delves into the effectiveness of AI in advancing STEM education and reveals that the strategic integration of AI holds significant potential for enhancing STEM education, such as AI facilitates personalised learning, advanced analytics and instructional automation, resulting in improved learning outcomes for students in STEM subjects. However, Triplett also highlights practical challenges that educators and policymakers must address to implement AI successfully in STEM education. Despite these challenges, the research emphasises the importance of strategic AI integration and its positive impacts on enhancing personalised learning and instructional approaches in STEM education.

Transitioning from the exploration of AI, our journey continues into the realm of the metaverse. The metaverse is a collective of virtual shared space created by the convergence of physical and VR (Wang et al. 2022) and represents a conceptual evolution of the internet. The transformative potential of the metaverse, coupled with fifth-generation communication, blockchain and non-fungible tokens (NFTs), reshapes the boundaries between physical and virtual realms (Uddin et al. 2023). Highlighting the transformative potential of the metaverse, Uddin et al. (2023) discuss the role of fifth-generation communication, blockchain and NFTs in seamlessly integrating physical and virtual elements. Non-fungible tokens are unique digital tokens representing ownership or proof of authenticity for specific digital or physical assets. Each distinctive NFT cannot be divided into smaller units and resides on a decentralised and transparent blockchain. The blockchain ensures the secure and transparent recording of ownership details and the uniqueness of each token. Challenges in navigating metaverse implementation's complexities encompass hardware advancements, regulatory frameworks, security measures, sustainability and potential risks, particularly those linked to the 'darkverse', and highlight the necessity for environmentally sustainable practices through green metaverse initiatives (Uddin et al. 2023). Uddin's study envisions a path towards enhanced security and privacy measures, recognising the pivotal role of NFTs in fostering a safer, more immersive metaverse experience. Together, these insights highlight the imperative nature of addressing multifaceted aspects for the successful and sustainable integration of the metaverse. The incorporation of NFTs into education represents a dynamic and rapidly evolving frontier. The diverse applications of NFTs within educational contexts are still unfolding, and delineating the most efficacious and ethically sound approaches requires ongoing efforts by educators, technologists and policymakers. The evolving nature of this intersection underscores the need for ongoing exploration and collaborative efforts to harness the full potential of NFTs in enhancing educational experiences.

The focus now shifts to the crucial role of community partnerships and funding to ensure the accessibility of these advancements to all. Together, these insights build a comprehensive narrative that underscores the seamless integration of diverse technologies, painting a vivid picture of emerging technologies interconnected and transformative nature in education.

■ Community partnerships and innovative funding models

In pursuing equitable access to technology in education, moving beyond theoretical discussions and exploring practical strategies is essential. Chapter 1 discussed the socio-economic inequality in South African schools. The digital divide encompasses variations in digital access and skills among individuals, households, businesses, or geographic areas (OECD 2001; Pick & Sarkar 2016), particularly rife in African countries where the term generally refers to a population split based on access to and literacy in technology (Gyamfi 2005) that result in significant economic, political and social consequences (Hameed 2006).

Addressing the digital divide requires concerted efforts, and community partnerships and innovative funding models emerge as tangible solutions. One impactful approach to bridge the digital divide involves fostering collaborations with community organisations. By engaging with local partners, educational institutions can tap into existing resources and networks to provide technology resources and internet connectivity to underserved populations. This collaborative effort extends beyond the confines of educational institutions, reaching into the heart of communities and ensuring that technology becomes a shared resource.

Community partnerships, exemplified by organisations like Women in Tech Africa (WITA), are pivotal in bridging the digital divide and ensuring equitable access to technology for learners across Africa. Women in Tech Africa, with a vast membership spanning 30 countries globally and 12 physical chapters, is a beacon for promoting the capabilities of African women in technology. Through projects such as incubating female tech entrepreneurs and inspiring young girls into STEM careers, WITA actively contributes to narrowing the digital gap. By focusing on entrepreneurship, career support, and fostering interest in STEM fields, WITA aligns with its mission to ensure African growth through technology. The organisation's efforts, recognised by the United Nations Equals Award, exemplify the impact that community partnerships can have in creating a more inclusive and technologically empowered educational landscape. Through these partnerships, learners, particularly women, are empowered to harness the opportunities of the digital era, fostering a more diverse and skilled workforce for the future.

In line with the above, the Connekted Girls Hub contributes to bridging the digital divide by addressing the challenges women and girls face in accessing and succeeding in STEM fields. The platform facilitates collaboration between government, the private sector and civil society to create a more inclusive and gender-equal digital landscape in Africa (UN Woman Africa 2022).

The Science Learning Centre for Africa (SLCA), an extension of the University of the Western Cape's School of Science and Mathematics Education, has initiated a Coding and Robotics club to train teachers in Coding and Robotics (University of the Western Cape 2022). This programme involves schools from various areas and provides short courses for teachers, exposing learners to cutting-edge technology. The initiative emphasises the importance of enhancing science and mathematics education, promoting self-directed and PBL. It addresses the forthcoming inclusion of coding and robotics in South Africa's national curriculum, highlighting their role in fostering innovative thinking. Learners can explore technology like drones, inspiring potential careers in science and ensuring a more equitable educational landscape. This project exemplifies how community partnerships in education contribute to bridging the digital divide, particularly in under-resourced communities.

Anglo American's Education Programme aims to enhance inclusive and quality education. It illustrates the significance of community partnerships in education, particularly in bridging the digital divide in South Africa (Anglo American 2018, 2022). The programme involves partnerships with teachers to improve technology skills and a recent focus on learners through the ICT Education Project. The project collaborates with various stakeholders, including infrastructure providers, content creators, device providers, civil society and the Department of Basic Education (DBE), to develop an effective model for ICT implementation in lower-quintile schools. The skills developed through this programme prepare young people for the Fourth Industrial Revolution (4IR). The chapter underscores the challenges faced by schools.

Notably, Anglo American projects emphasises the need for a comprehensive approach involving teachers, relevant content, devices, bandwidth and entrepreneurial skills for learners. The partnership approach extends to repurposing technology devices, minimising electronic waste, and seeking collaborations with corporate South Africa. The commitment to zero-rate all educational content aims to reduce costs for students and schools, further highlighting the community-centric approach. The community-focused collaboration aims to empower teachers and students, create a conducive environment for SDL, and integrate technology into teaching methods to prepare young people for the opportunities of the Digital Age.

The financial aspect of acquiring and maintaining up-to-date technology infrastructure can be a barrier for many educational institutions. Exploring creative funding mechanisms becomes paramount. Innovative funding models, such as public-private partnerships, grants, or community-driven initiatives (Broadband Commission for Sustainable Development, ITU & UNESCO 2021), can provide sustainable support for schools' quest for technology integration. These models secure initial investments and ensure ongoing access to evolving technological resources.

The Technology Innovation Agency (TIA) in South Africa has funded FibrePoynt, a start-up developing an alternative, cost-effective internet solution for low-income communities, reducing infrastructure costs by over 50% (Silaule 2021). This initiative addresses financial barriers and emphasises inclusivity by empowering local entrepreneurs and communities through an innovative internet service provider (ISP) model. The success of FibrePoynt demonstrates the effectiveness of public-private partnerships and targeted funding in achieving sustainable and equitable access to technology in educational settings.

Additionally, initiatives like IkamvaYouth, funded through The David and Elaine Potter Foundation, a South African organisation relying on volunteers and ex-beneficiaries, demonstrate the impact of community-driven approaches in providing educational support and opportunities. These examples underscore the significance of adopting innovative funding models to sustain technological access and bridge educational disparities (Machikicho 2023).

Actionable design principles for enhancing self-directed learning with emerging technologies in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education

Integrating emerging technologies in STEAME education is a transformative journey that requires actionable design principles to empower SDL. Drawing insights from the rich literature discussed in the previous sections on *IoT* (Department of Education 2001; Kent et al. n.d.; Liston et al. 2022; Palanivel 2019; Thornhill-Miller et al. 2023; Todorov & Vela 2023), *gamification* (Botha-Ravyse et al. 2018; De Troyer et al. 2019; Lampropoulos et al. 2022; Mutekwe 2022; Palaniappan & Noor 2022; Ratinho & Martins 2023), *virtual and AR* (Brij & Belhadaoui 2021; Grewe & Gie 2023; Huang et al. 2020; Kazu & Kuvvetli 2023; Kenwright 2018; Moreno 2006; Veermans & Jaakkola 2021; Zain 2023; Marrahi-Gomez & Belda-Medina 2024; Lampropoulos 2023; Tene, Marcatoma Tixi, Palacios Robalino, Mendoza Salazar, Vacacela Gomez & Bellucci 2024), *AI* (Malaise & Signer 2023; Qushem et al. 2003; Saadé et al. 2023; Sung et al. 2021; Triplett 2023) and the *metaverse* (Uddin et al. 2023; Wang et al. 2022) offers a comprehensive framework (Table 12.2) for educators, curriculum developers and stakeholders seeking to enhance SDL with emerging technologies.

TABLE 12.2: Actionable design principles for enhancing self-directed learning with emerging technologies in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education.

Recommendation	Principle	Implementation
Cultivate context-aware learning environments	Design learning environments that dynamically adapt to students' contextual needs, leveraging the IoT capabilities	Integrate smart sensors and IoT technologies to create responsive educational spaces; this integration allows real-time monitoring and personalisation of learning experiences based on individual progress, preferences, and environmental factors.
Gamify learning experiences for intrinsic motivation	Infuse gamification strategies to promote autonomy, active participation and intrinsic motivation in learners	Incorporate challenges, rewards and interactive narratives within the curriculum, aligning with the principles of self-directed learning. Utilise gamified elements to enhance engagement, commitment and academic performance.
Immerse learners in virtual and augmented realities	Utilise immersive technologies, such as virtual reality (VR) and augmented reality (AR), to provide real-world simulations and enhance experiential learning	Integrate VR and AR experiences that allow students to practically apply theoretical knowledge, fostering a deeper understanding of complex STEAME concepts. Ensure a balanced approach that considers both enjoyment and educational outcomes.
Harness the power of artificial intelligence for personalisation	Leverage AI to tailor learning experiences, providing personalised content and challenges based on individual progress and preferences	Implement AI-driven adaptive learning systems that analyse student performance, identify challenges, and offer customised learning paths. Integrate natural language processing (NLP) and computer vision for interactive and intelligent interfaces.

Table 12.2 continues on the next page→

TABLE 12.2 (cont.): Actionable design principles for enhancing self-directed learning with emerging technologies in Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship education.

Recommendation	Principle	Implementation
Navigate the metaverse responsibly	Embrace the transformative potential of the metaverse while addressing ethical considerations and ensuring responsible integration	Explore the use of the metaverse to create shared virtual spaces for collaborative learning. Consider issues such as digital identities, privacy, and ethical data use. Engage students in discussions about responsible and ethical behaviour in the virtual realm.
Ensure inclusivity through emerging technologies	Foster inclusivity by addressing challenges related to accessibility, the digital divide and diverse learning needs	Design technology-enhanced learning experiences with accessibility in mind, considering the needs of all learners, including those with disabilities. Implement strategies to bridge the digital divide and provide equitable access to emerging technologies.
Promote interdisciplinary collaboration	Encourage collaboration among educators, technologists, researchers and policymakers to harness the full potential of emerging technologies	Facilitate interdisciplinary discussions and collaborations to address the evolving technology landscape in education. Promote a collective understanding of effectively integrating emerging technologies into STEAME education.
Integrate blockchain and NFTs for credentialing	Revolutionise credentialing processes using blockchain technology and NFTs to provide transparent and tamper-proof records of students' achievements	Explore blockchain solutions for secure credentialing and verification. Utilise NFTs to authenticate and validate digital assets within educational contexts, ensuring the integrity of student achievements.

Source: Authors' own work.
Key: NFT, non-fungible token; AR, artificial reality; VR, virtual reality; IoT, internet of things; STEAME, Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship.

These actionable design principles aim to guide educators and stakeholders in creating immersive, adaptive and inclusive learning environments that leverage the transformative potential of emerging technologies in STEAME education. By embracing these guidelines, educational practitioners can foster SDL, enhance student engagement and prepare learners for the dynamic challenges of the 21st century.

■ Key insights

The pivotal insights gleaned from our exploration of emerging technologies in education underscore their transformative impact across various educational approaches. In the context of SDL, AI facilitates the customisation of content and pace to foster personalised experiences and encourage autonomy. Virtual reality/augmented reality creates immersive environments, enabling self-directed exploration, while IoT contributes to smart learning environments with real-time monitoring. Gamification strategies further enhance autonomy and engagement through challenges and interactive narratives. Problem-based learning benefits from real-time feedback provided by AI, realistic simulations facilitated by VR/AR and diverse opportunities for problem-based exploration with IoT. Gamified systems in PBL introduce challenges and narratives, fostering problem-based exploration. In cooperative learning, AI enhances adaptive systems, gamified elements in VR/AR boost engagement, IoT fosters collaboration and gamification enhances group dynamics. Within the realm of gamification, AI augments systems intelligently, VR/AR introduces interactive elements and IoT-based systems incorporate game-like elements, all promoting engagement and motivation. Ongoing studies underscore the positive impact of gamification on academic performance and SDL. These insights emphasise the diverse ways emerging technologies can be leveraged to enhance various educational approaches, promoting engagement, autonomy and collaboration in dynamic learning environments.

■ Overarching impact

The inclusion of emerging technologies in the educational landscape offers dynamic and inclusive environments for learners. These technologies bridge gaps in access and cultivate a generation prepared to navigate the challenges and opportunities of tomorrow. Collaborative efforts required to bridge the digital divide, coupled with advancements in the IoT, promise more innovative and responsive learning experiences.

Across different technological pillars, recurring themes underscore the importance of inclusivity, ethical considerations and continuous adaptation. Challenges such as infrastructure development, resource allocation and ethical use of AI highlight the complexity of integrating emerging technologies into education. This chapter applied theoretical frameworks, including the COI, critical realism and the Integrated lens, to highlight technology integration's social and collaborative aspects and explore underlying structures shaping the educational landscape.

The COI framework helped illuminate the social and collaborative aspects of technology integration. By examining the interplay between technology, pedagogy and social presence, we gained insights into how communities of learners engage with emerging technologies. Adopting a critical realist perspective allowed us to explore the educational landscape's underlying structures. This lens enabled us to distinguish between the observable challenges and the deeper, often systemic issues influencing the integration of emerging technologies. The Integrated lens, synthesising various theoretical perspectives, provided a comprehensive understanding of the multifaceted nature of the identified themes. By combining insights from diverse lenses, we navigated the complexities inherent in the intersection of technology and education.

By employing these theoretical frameworks, our study aimed to identify common themes and challenges and provide a nuanced understanding of the underlying dynamics. The theoretical lens enhanced the interpretative depth, contributing to the scholarly discourse on integrating emerging technologies in education.

Conclusion

Our exploration of emerging technologies and the immersive realms of VR and MR, enriched by AI and data analytics insights, unfolds the transformative landscape of modern educational paradigms. The integration of actionable strategies, such as community partnerships, innovative funding models and practical design principles for enhancing SDL through emerging technologies, contributes collectively to a comprehensive understanding of the intersection between technology and education. Looking forward, future research directions emphasise exploring the evolving impact of emerging technologies on education and investigating the application of gamification in teacher professional development. In conclusion, this journey into the transformative potential of emerging technologies in education continues to evolve with each technological advancement and educational insight. Embracing a holistic approach to STEAME education, it converges technology, pedagogy and knowledge to shape a dynamic and inclusive educational landscape, preparing generations for future challenges and opportunities.

Chapter 13

Reasoning backwards with the aid of visual diagrams to solve a calculus problem

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Abstract

This chapter provides a reflection on the mathematical moves two pre-service mathematics teachers (PMTs) invoked and applied to solve a calculus problem by using the working backwards problem-solving strategy. The problem allows students to engage with meaningful mathematics through self-directed learning, critical and creative thinking, and using visual aid diagrams to solve a calculus problem using differentiation. This approach emphasises the necessity for students to use 21st-century core competencies and creative tactics, such as the working backwards chain reasoning strategy, to solve challenges, particularly the accident scenario presented in this chapter and analogous real-life difficulties in this disruptive period. The sample of the study involved 58 second-year PMTs doing the Bachelor of Education (BEd) Senior Phase programme. The data were collected through a task-based activity and video recording of the students' solutions. Content analysis was utilised

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to establish the salient mathematical moves PMTs enacted to solve a cubic function graph problem. Results showed that when PMTs are given opportunities to work on complex problems, they can on their own select a problem-solving strategy like the 'backwards strategy' to solve a graph problem using self-generated visual diagrams to visually reason backwards in a sequential manner using first derivatives and second derivatives. This example illustrates that when fodder is provided for self-directed learning and creative and critical thinking, students can provide innovative solutions to a problem.

Introduction

Students need to have the ability to solve problems as a prerequisite to advance to higher-level skills like critical and creative thinking (Nurlaily, Jannah & Wijayanti 2021). Safitri (2018) asserts that the integration of communication, problem-solving, representation, comprehension, reasoning and linkages will enhance the quality of the mathematics learning process. As a result, through solving problems, students will get useful knowledge in mathematics (Inganah, Vidyastuti & Sah 2023). In solving problems, students can select and apply any one of the following strategies or a combination of strategies: Engage in guess/conjecture and verification, seek patterns, compile a systematic enumeration, illustrate concepts using pictures, discard infeasible options, tackle a more straightforward problem, apply principles of symmetry, utilise a conceptual model, examine special instances, work backwards, employ deductive reasoning, apply established formulas, solve equations and exhibit creativity. According to Utomo (2019), some problems have several features, some can be treated with a single strategy and some require a combination of approaches. Finding the greatest and most effective problem-solving strategies is often related to the students' experience and expertise. As stated by Inganah et al. (2023), working backwards is one of the problem-solving strategies that can be used when learning.

According to Andinasari et al. (2019), the process of working backwards involves first understanding how to accomplish the desired outcomes. This method allows the problem to be solved by starting with what is known and asking questions, then adjusting both to find the solution. In the context of problem-solving, students are naturally able to efficiently analyse actions in reverse order when faced with a sequence of events where the eventual result is known but the initial conditions are unknown (Inganah et al. 2023).

Working backwards is the most challenging task for students, according to Pebrianti, Juandi and Nurlaelah (2022), because they do not fully grasp the concepts. They went on to say that the primary cause of low reversible thinking skills in students is their incapacity to draw connections between ideas, processes and principles, which makes it challenging for them to employ reasoning or backwards thinking to solve problems. Through my personal teaching experience, as a senior high school teacher, college lecturer and university professor of mathematics education, I have come to see and believe that diagrams can facilitate learners' comprehension of key concepts within a problem and aid learners in achieving the correct solutions or proofs. Hence, the purpose of the inquiry in this study was to investigate how reasoning (working) backwards with the aid of visual diagrams could assist to some extent in solving a calculus problem. In doing so, this research highlights the nexus between problem-based learning and self-directed learning.

The chapter presents the analysis of how a given calculus problem was solved by Bachelor of Education (BEd) students during one of their BEd Mathematics Education 3 class work activity lectures.

Working backwards strategy approach to problem-solving

Every single day, investigators conducting traffic accidents employ the working backwards technique. In order to reconstruct an automobile accident, the police investigating the incident must start at the moment of impact and work their way backwards to determine what caused it, which vehicle swerved just before the collision, who collided with whom, which driver was at fault, what the weather conditions were like, etc. We use this strategy when a person is planning to take a flight for example. One often starts with the departure time of the flight and then works backwards to the boarding time and check-in timeto arrive at a time that one must depart from home/work to arrive at the airport. Although we use this problem strategy quite often in everyday-life decision-making situations, it is not a natural method to call on when tackling a mathematics problem.

The following example illustrates the elementary use of the working backwards strategy at a lower primary school level.

Problem

James was broke when he received his weekly allowance on Monday. On Tuesday, he spent ZAR26.50 of the allowance. On Wednesday, his brother pays him the ZAR21.50 he owes him. How much is James's allowance if he now has ZAR55.00?

Solve the problem

ZAR55 − ZAR21.50 (the money given by his brother) = ZAR33.50.

Now add the money spent on Tuesday, that is, ZAR26.50. The total becomes ZAR60.00, which is James's weekly allowance.

Not only that, but occasionally we find really helpful strategies offered in the processes that students are shown in their standard textbook exercises. Regrettably, students are frequently unaware of this and take them for granted. Despite not having been instructed to do so, students could be expected to reason in reverse order. The process one should follow when creating proofs in a high school geometry subject is a clear illustration. Before they do anything else, they ought to look at what they are attempting to show. Therefore, an attempt to prove line segments congruent could possibly require a student to prove that a pair of triangles is congruent. This, in turn, should suggest that students search for the components required to achieve this triangle congruence. As we proceed in this fashion, the students will be guided to investigate the material that has been provided. In essence, they are 'working backwards'. Working backwards, often known as backwards chaining, is an inference method that involves working backwards from the target or goals (Rusell & Norvig 2009, p. 337). A problem may contain a series of actions from the end to a desired point in the action sequence. The main task here is to find the starting point. Retrospectively, when the objective is unique and there are numerous starting points, an intelligent problem solver will begin to move backwards from the intended conclusion to a point where the information that is provided is reached.

Sweller (1988) advocates the notion that forward reasoning tends to align more with typical mental models, as people prefer to move from known to unknown conditions. Within the same mindset, Larkin and Simon (1987) affirm that reasoning from initial conditions forward to a logical solution or conclusion is aligned with the natural way people solve problems. Similarly, if you were to describe a chain of events to the average person, they would very certainly predict the outcome. They can mentally assemble those and use them as evidence that something will happen. On the other hand, very few people could, given a result, automatically deduce, from their own internal processes, what actions had preceded it. When I speak about thinking analytically or in a backwards way, I imply this power. Determining the sought from the supplied difficulties to identify or the statement to validate the assumptions is what makes working backwards distinctive. When working on the problem, this momentarily shifts the focus: from an unknown or untested goal, a previously unknown solution path is constructed step-by-step, which should subsequently allow the problem solver to move in the other direction (Assmus & Fritzlar 2022).

Although many research papers, mathematics didactic textbooks and teaching materials assign problems or their answers to strategies that do not align with this theoretical viewpoint, this view is generally held. The working backwards strategy has been applied to mathematical problems by researchers (Katz, Segal & Stupel 2016; Posamentier & Krulik 2015; Portnov-Neeman & Amit 2016), but no research has been done to exemplify the use of the backwards strategy with the aid of visual diagrams to solve a calculus graph problem through using differentiation techniques as demonstrated by pre-service mathematics teachers (PMTs) in Figure 13.1 and Figure 13.2.

Visualisation and understanding of derivative graphs

A growing body of literature supports that mathematical thinking is anchored on spatial competence. According to Duval (1995), '[*t*]here's no knowledge that can be mobilised by an individual without a representation activity' (p. 15). Zazkis, Dubinsky and Dautermann (1996) are of a similar view and mention that mathematical problem-solving starts with visualisation. Thus, student visualisation and analytical reasoning go hand-in-hand during the problem-solving process (Zazkis et al. 1996). Henceforth, for a student to construct a deep understanding of mathematical reasoning requires both spatial visualisation skills and analytical reasoning. Thus, visuals such as graphs, sketches or diagrams communicate mathematics ideas which help 'in connecting ideas across the problem given' (Ho & Lowrie 2014). As such, the ability to use a sketch or graph to depict a problem aids in the understanding of the problem solution.

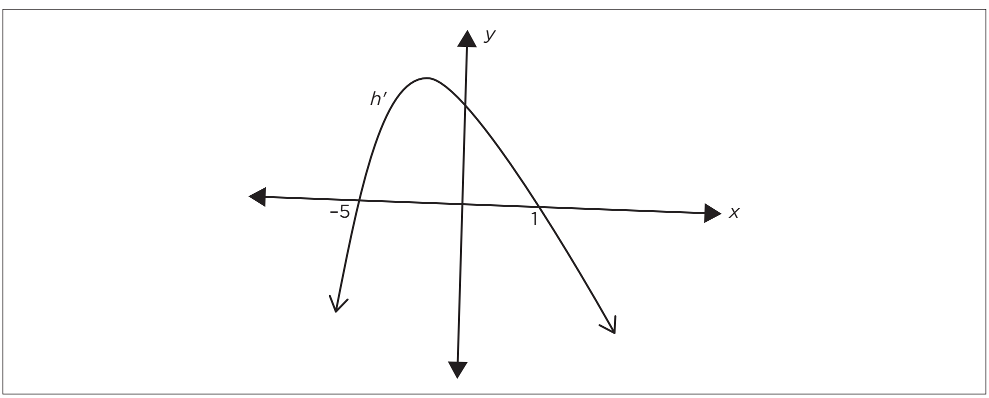
Park and Brannon (2013) contend that even when we work on simple arithmetic, such as 12 + 11, with symbolic digits (12 and 11) our mathematical reasoning is grounded on visual processing. Also, from the pioneering work of Krutetskii (1976), it was found that 'students of the analytic type do not strive to make the problems visual, and this results in a certain one-sidedness in their mathematical development' (p. 321). In response to this inconclusive statement, Zimmermann and Cunningham (1991) conducted research among high school learners about their understanding of calculus. Their finding shows that many of the students have difficulty in problem-solving. Zimmermann and Cunningham (1991) concluded that the student's inability to solve the problem is because of their inability to visualise. According to Engelbrecht and Harding (2005) and Vinner (1997), most educators and learners quite often exhibit misconceptions about cognitively demanding concepts such as inflection points. Vinner (1997) attests that this is often attributed primarily to their concept image and inner struggle with formal definitions versus intuitive understanding.

García-García and Dolores-Flores (2021) attribute students' difficulty in connecting algebraic functions to graphical representations to the traditional method that tends to emphasise on sketching of graphs from algebraic or tables, but less is done on the reverse. Thus, students find it easy to sketch the graph of an algebraic function but struggle to visualise and transform derivative graphs into algebraic functions.

According to Posamentier, Smith and Stepleman (2010), graphical issues (like derivative graphs) are presumed to involve a sequence of activities from the beginning to a desirable point in the action sequence. Posamentier and Krulik (2008) contend that working backwards is a potent problem-solving technique, but the key is figuring out where to begin. Based on the aforementioned, students' difficulty in solving problems on derivative graphs can be attributed to the inability to visualise, backwards reasoning and where to start.

Illustrative example

The sketch shows the graph of $h'(x)$ with x-intercepts at −5 and 1. Draw a sketch graph of $h(x)$ if $h(-5) = 2$ and $h(1) = 6$.

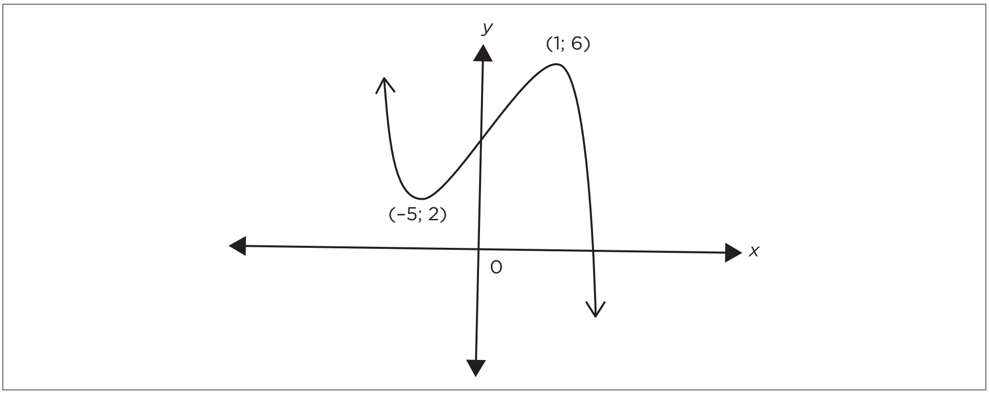


Source: Author's own work.

FIGURE 13.1: The graph of $h'(x)$ with x-intercepts at −5 and 1.

Problem solution

Firstly, the student has to start by knowing that $h(x)$ is a cubic function because $h'(x)$ is a parabola. As such, the student needs to apply the reverse reasoning by visualising that $h(x)$ has two turning points because $h'(x)$ has two x-intercepts. Hence, the x-values of the turning points of $h(x)$ are the two x-intercepts of $h'(x)$, where $h'(x) = 0$. So $h(x)$ will have turning points at (−5; 2) as the minimum turning point and at (1; 6) as the maximum turning point. Henceforth, the cubic graph can be sketched as in Figure 13.2.



Source: Author's own work.
FIGURE 13.2: Cubic graph.

Diezmann (2005) affirms that diagrams do support visual reasoning and can serve as cognitive tools to develop logical arguments and make plausible deductions. Hence, it is imperative for teachers to explore and become conversant with pedagogical tools and emerging pedagogies that can enable learners to use diagrams meaningfully as cognitive tools to solve challenging problems with success.

Research design and methodology

This study employed a qualitative methodology utilising a case study research design to enable the researcher to obtain comprehensive and nuanced information (Barbie & Mouton 2010) regarding the degree to which pre-service teachers utilise visual diagrams in reasoning backwards to identify problem-solving initiation points (Inganah et al. 2023). Data were collected via video recordings as two PMTs presented their solutions to the calculus problem (called a mathematical task) to their 58 peers in their mathematics class. The videos captured students' use of diagrams and written solutions, as well as their reasoning and explanation as they presented their solutions to their classmates. The researcher analysed the videos. Images of their solutions, which they were writing on the classroom whiteboard as they were presenting and explaining the solution to their peers, were extracted in the form of still pictures. These still pictures serve as transcripts for much more detailed content analysis. Qualitative content analysis helped identify the salient steps and reasoning as they presented their solutions to their classmates. The video data were coded using a pre-established coding scheme based on the study's research question. Codes were assigned to instances of the use of visual diagrams and backwards reasoning.

Mathematical task

One of the main topics that the student teachers do in the BEd Mathematics Education content module is differential calculus. We start with the average gradient concept and move onto the limit concept, derivatives from first principles, rules of differentiation, curve sketching using the first derivative approach, interpretation of graphs grounded on the first derivative approach, second derivative approach in relation to concavity, point of inflection and curve sketching, and related maxima and minima calculus problem. At the time, when the following mathematical problem was given to the students to do, they were not yet exposed to the second derivative approach in relation to concavity, point of inflection and curve sketching:

Problem

The curve of $f(x) = ax^3 + bx^2 + cx + 5$ has a stationary point at $x = 0$.

The point (2, −11) lies on the curve.

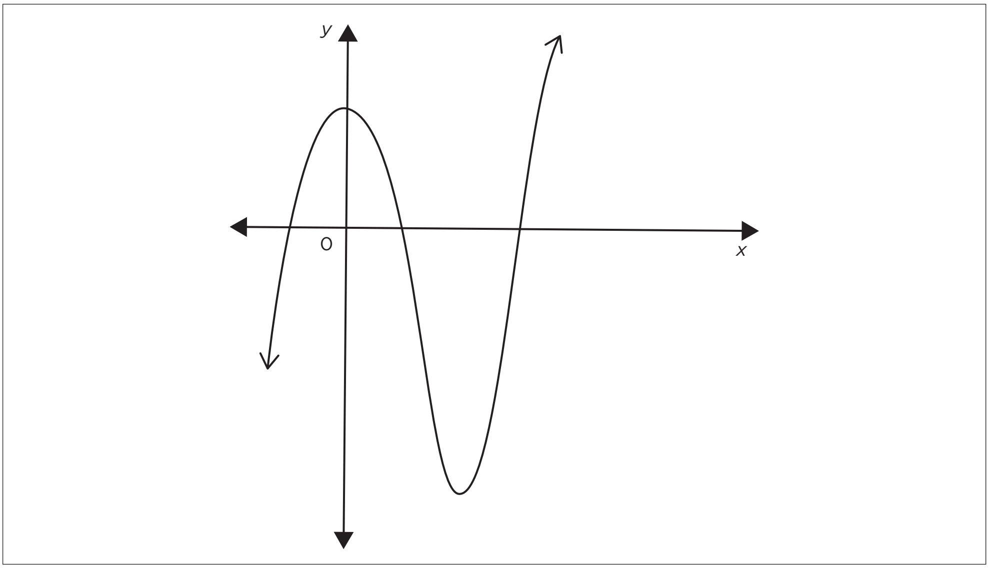
$\frac{d\left(f'(x)\right)}{dx} = 0$ when $x = 2$

1.1 Determine the values of *a*, *b* and *c*.

1.2 Where does the relative minimum point occur?

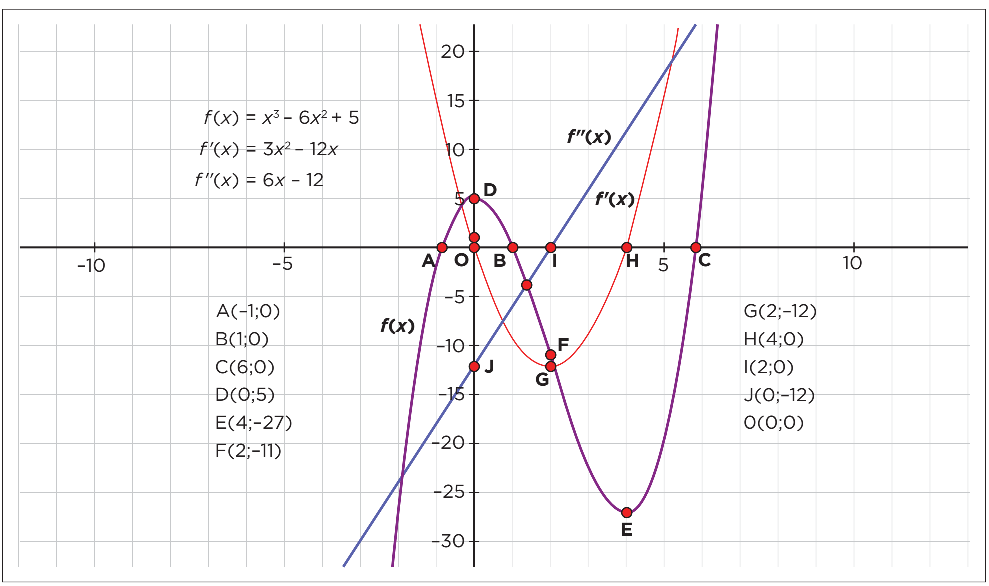
For this purpose, I refer to the graph of a cubic function defined by $f(x) = x^3 - 6x^2 + 5$ (see Figure 13.3). In Figure 13.4, the relationships between the graphs of *(x)*, *f′(x)* and *f″(x)*, as discussed hereafter, are illustrated.

- The derivative, *f′*(*x*), of a cubic function, *f*(*x*), is a quadratic function. When we differentiate this quadratic function, *f′*(*x*), we call it the second derivative of the original function. The second derivative is a linear function. The notation for the second derivative is *f″*(*x*).
- The zero points of the first derivative give the *x* coordinates of the turning points of the cubic function defined by *f*(*x*).
- The *x* coordinates of the turning points of the cubic function defined by *f*(*x*) maps vertically onto the respective *x* coordinates of the *x*-intercepts of the graph of the quadratic function.
- The zero point of the second derivative gives the *x* coordinate of the turning point of the quadratic function defined by *f′*(*x*), that is, first derivative as well as the *x* coordinate of the point of inflection (see further discussion of point of inflection later) of the cubic graph defined by *f(x*).
- The *x* coordinate of the turning point of the graph defined by the quadratic function, *f′*(*x*), maps vertically onto the respective *x* coordinate of the *x*-intercept of the graph of the linear function defined by *f″*(*x*).



Source: Author's own work.

FIGURE 13.3: Some salient features of the graph of a cubic function.



Source: Author's own work.

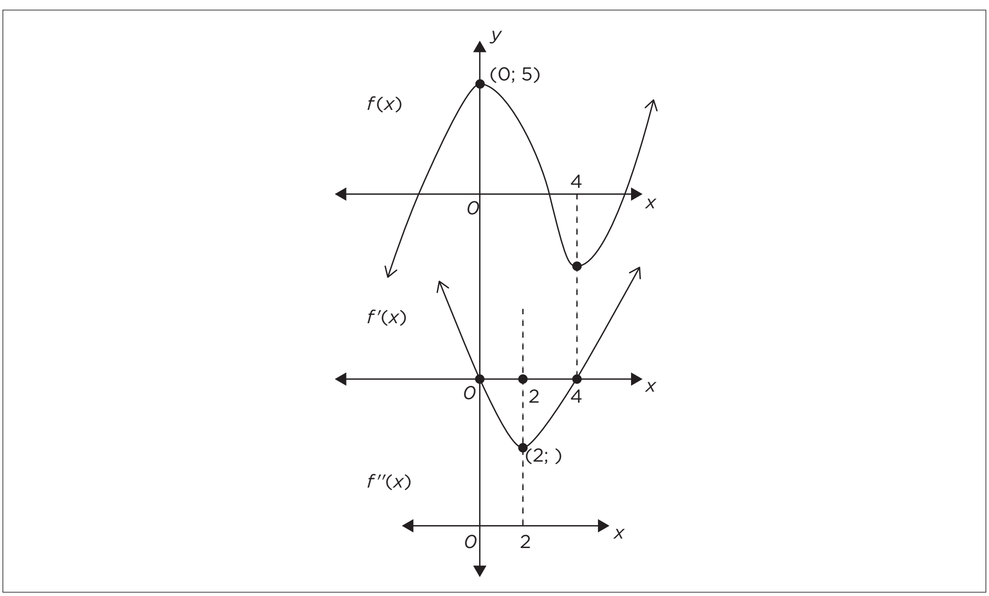
Figure 13.4: The graphs of $f(x)$, $f'(x)$ and $f''(x)$.

Interpretation of information in the given mathematical problem

With reference to the information given in the problem, one can make some plausible derivations and / or conclusions that could help to solve the problem. For example, when one considers the piece of information $\frac{d\left(f'(x)\right)}{dx} = 0$ when $x = 2$, the first thing that should come to mind is 'what does this mean' with respect to either the graphs of $f(x)$, $f'(x)$ and $f''(x)$. Firstly, in no particular order, one could equivalently say $f''(x) = 0$, when $x = 2$, which could equivalently be written as $f''(2) = 0$. Secondly, as discussed for the graph of $f(x)$, the statement $f''(x) = 0$, when $x = 2$, can be similarly applied backwards to chain the idea that the turning point of the parabola defined by $f'(x)$ exists at $x = 2$. Thirdly, $f''(x) = 0$, when $x = 2$, one could logically conclude that a point of inflection exists at $x = 2$, which is $(2, f[2])$, that is $(2, -11)$. So, the given point $(2, -11)$ is an interesting point in that it is a point of inflection.

With all the aforementioned information in the background, I proceed to present and analyse the responses of two students (namely Carel and Mathew) with respect to their use of diagrams coupled with the working backwards strategy to solve the given problem.

Case 1: Carel's response



Source: Author's own work.

FIGURE 13.5: Carel's response.

As evident in the transcript extracted from the video clip of Carel's response to the solution to the problem, which he presented to his class in an interactive manner, we see that Carel reasoned backwards with the aid of visual diagrams to solve the problem. As shown in Figure 13.5, he drew those three diagrams on the whiteboard. Hence, I summarise the moves Carel made in constructing and making sense of the problem in terms of the given problem as follows:

Move 1: Carel seemed to have interpreted from the given piece of information $\frac{d(f'(x))}{dx} = 0$ when $x = 2$, that the x-intercept of the graph of $f''(x)$ is (2,0), and knowing that the x coordinate of the turning point of the graph defined by the quadratic function, $f'(x)$, maps vertically onto the respective x coordinate of the x-intercept of the graph of the linear function defined by $f''(x)$, he worked backwards to deduce that the x coordinate of the turning point of the quadratic function, $f'(x)$, is 2.

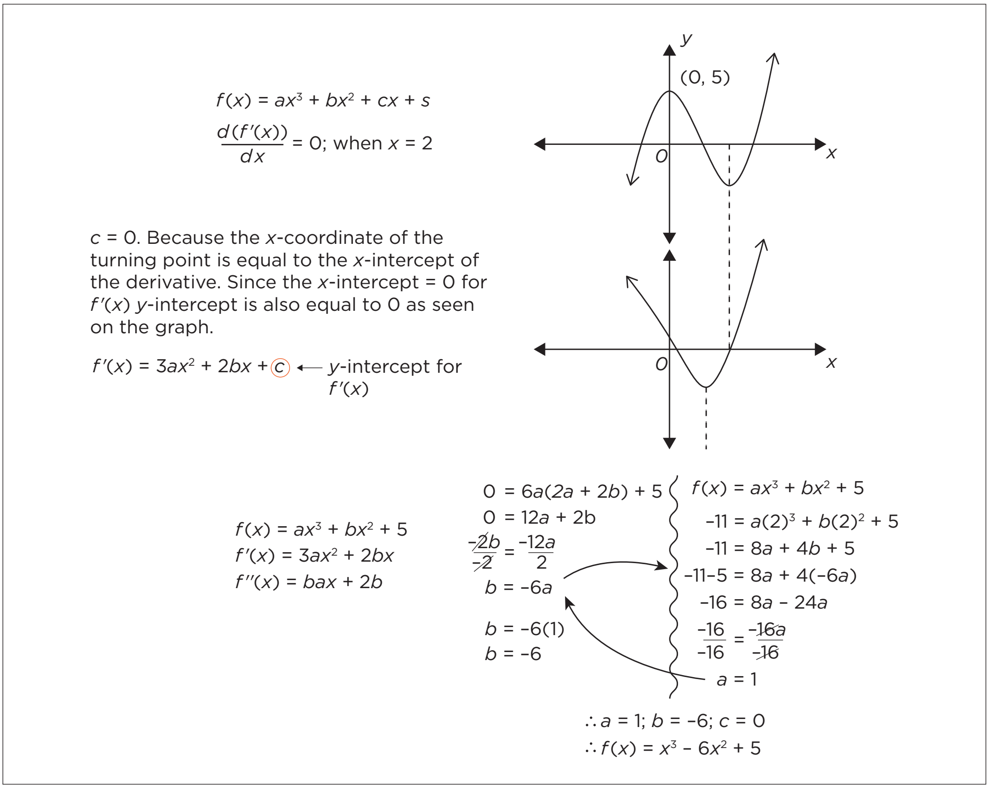
Move 2: From the given function $f(x) = ax^3 + bx^2 + cx + 5$, it seems that Carel has rationalised that the y-intercept of the graph of $f(x)$ has the y-intercept (0,5), and as per the given sketch of the graph of $f(x)$, that (0,5) has to be the coordinates of one of the turning points of the graph of $f(x)$. Using the fact that the x coordinates of the turning points of the cubic function defined by $f(x)$ maps vertically onto the respective x coordinates of the x-intercepts of the graph of the quadratic function, Carel worked backwards with the aid of his diagrams to conclude that the graph of $f'(x)$ passes through the point (0,0).

Move 3: Using his quadratic theory knowledge and his experiences with the sketching of the graph of a parabola, Carel articulates that the line of symmetry of the parabola passes through (2,−4), and considering we have one of the intercepts of the parabola, namely (0,0), proceeds to calculate the x coordinate of the second x-intercept of the graph of $f'(x)$ through the use of symmetry. He thus gets the second x-intercept that the graph of $f'(x)$ to be (4,0) as can be seen on the second graph in Figure 13.5.

Move 4: Now knowing that the zero points of the first derivative give the x coordinates of the turning points of the cubic function defined by $f(x)$, he works backwards with the aid of his diagrams to establish that the x coordinate of the second turning point of $f(x)$ is 4, as can be seen in Figure 13.5.

Case 2: Mathew's response

Mathew has made a connection between the graph of $f(x)$ and $f'(x)$. He has articulated that '[...] the x coordinate of the turning point is equal to the x-intercept of the derivative'. Even though he does not seem to realise the



Source: Author's own work.

FIGURE 13.6: Mathew's response.

difference between the notions 'x coordinate' and x-intercept, he does evidently demonstrate through visual representation the connection between the graph of $f(x)$ and $f'(x)$ by drawing a vertical broken line that passes through a turning point of $f(x)$ and a corresponding but a related point (called the x-intercept) on the graph of $f'(x)$. In addition, as you see in Mathew's diagrammatic representation (Figure 13.6), there is a connection between the maximum turning point (0,5) of the graph of $f(x)$ and the x-intercept (namely, (0,0). This in essence, means that Mathew has conceptually realised that a stationary point of $f(x)$ can be mapped as an x-intercept of the graph of $f'(x)$ (see Figure 13.6).

Retrospectively, if we were given $(x) = x^3 - 6x^2 + 5$, and asked to write down the coordinates of the x coordinates of the stationary points of f, then in working forwards, a student is expected to determine $f'(x)$, set $f'(x) = 0$, and then solve $f'(x) = 0$ to determine critical x-values (i.e. the roots of f'[x]), which are the corresponding x coordinates of the stationary points of f. Taking cognisance of these forward moves, and having access to the given piece of information that $f(x)$ has a stationary point exist at $x = 0$, Mathew worked backwards to rationalise that this equivalently means $f'(0) = 0$. By reflecting on the conceptual procedure of finding the y-intercept of any given graph, Mathew having realised that $f'(0) = 0$ worked backwards from the piece of information $f'(0) = 0$ to conclude that the y-intercept for graph of $f'(x)$ is (0,0).

Mathew, having calculated $f'(x) = 3ax^2 + 2bx + c$, realised that he could distil the value of c from his deduced information, namely that that the y-intercept for graph $f'(x)$ is (0,0), and this in essence is a typical move that characterises backwards chaining (or working backwards). Hence, Mathew, through the process of assimilation, managed to conclude correctly that $c = 0$.

Now, when one considers the piece of information $\frac{d\left(f'(x)\right)}{dx} = 0$ when $x = 2$, the first thing that should come to mind is 'what does this mean' with respect to either the graphs of $f(x)$, $f'(x)$ and $f''(x)$. As discussed earlier, one could equivalently say $f''(x) = 0$, when $x = 2$, which could equivalently be written as $f''(2) = 0$. Secondly, as discussed for the graph of $f(x)$, the statement $f''(x) = 0$, when $x = 2$, can be similarly applied backwards to chain the idea that the turning point of the parabola defined by $f'(x)$ exists at $x = 2$. Thirdly, $f''(x) = 0$, when $x = 2$, one could logically conclude that a point of inflection exists at $x = 2$, which is $(2, f[2])$, that is $(2, -11)$. So, the given point $(2, -11)$ is an interesting point in that it is a point of inflection.

Now reverting to Mathew's solution, he decided to work backwards through making the following moves to determine the values of a, b and c.

Move 1: Mathew determined $f''(x)$ in general terms to obtain a linear function as follows:

$$f''(x) = 6ax + 2b$$

Move 2: Mathew proceeded to use the linear function defined by $f''(x) = 6ax + 2b$ together with the given information $\frac{d\left(f'(x)\right)}{dx} = 0$, when $x = 2$, to establish that $b = -6a$, as follows:

$$\begin{aligned} 0 &= 6a(2) + 2b \\ 0 &= 12a + 2b \\ \frac{-2b}{-2} &= \frac{12a}{-2} \\ b &= -6a \end{aligned}$$

Move 3: Thereafter, working backwards Mathew considered the given information: the point (2; 11) which lies on the curve $f(x)$ From this piece of information, he sees that in the function described by $f(x) = ax^3 + bx^2 + cx + 5$, that when $x = 2$ then $f(x) = -11$. He thus proceeds as shown to substitute these values into $f(x) = ax^3 + bx^2 + cx + 5$ to obtain the equation $-11 = 81 + 4b + 5$.

$$f(x) = ax^3 + bx^2 + 5$$
$$-11 = a(2)^3 + b(2)^2 + 5$$
$$-11 = 8a + 4b + 5$$

Move 4: Mathew, thereafter, goes back to equation 1 and takes the value of b which is $-6a$, and then comes back to equation 2 and accordingly substitutes $-6a$ for b, and solves the resulting equation to obtain $a = 1$.

$$-11 - 5 = 8a + 4(-6a)$$
$$-16 = 8a - 24a$$
$$\frac{-16}{-16} = \frac{-16a}{-16}$$
$$a = 1$$

Move 5: Mathew reverts to his equation 1, and substitutes 1 for the value of a to obtain $b = -6$

$$b = -6(1)$$
$$b = -6$$

Finally Mathew summarises his determined values of a, b and c as follows:

$$\therefore\ a = 1;\ b = -6;\ c = 0$$
$$\therefore\ f(x) = x^3 - 6x^2 + 5$$

Source: Author's student responses for Moves 1–5, and Summary.

Discussion and findings

Critical thinking with a self-directed learning context fosters creativity by enabling the reasoner's total perspective to be expanded to mentally absorb and manage aspects that go beyond the rational (Matei 2023). Creativity is the process of opening up new options by identifying unanticipated spaces in issues that appear unsolvable to others. When creativity and critical thinking are combined, mathematical problems tend to be smartly solved. When the rest of us hardly even realise we are in a box, it is the capacity to think 'out of the box' (Matei 2018) that leads to the 'aha' moments in problem solving. Mathew's ability to think creatively aligns with Matei's (2023) assertion that creativity is essential. He employed a self-directed strategy to critically analyse and deduce that the constant c needs to be eliminated in order to determine the values of a and b's values (Arisoy & Aybek 2021).

Students' ability to reason in both normal and non-routine problem-solving processes can be enhanced by visual reasoning (Masduki, Savitri & Khotimah 2023) as evidenced in the sequential moves exemplified by the two students. The advantage of using visual diagrams as enabling tools in solving mathematical problems is that they can assist students in recognising significant connections between variables, quantities, and relational concepts that could help illuminate the pathway to a successful innovative solution like that exhibited by Carel and Mathew through backwards chaining (Jitendra 2019). From this discourse, it seems evident that students' effective or optimal employment of creative thinking strategies is directly aligned with the learning context and suitable educational environment organised by the facilitator (Sarrazy & Novotná 2013). Both students had the opportunity to participate in self-directed learning, so far that they had to, in Knowles's (1975, p. 18) parlance, set learning goals for themselves in order to solve the problems, and find relevant resources to facilitate their learning. This enhanced their critical thinking skills and allowed them to become more creative (Bishara 2021).

The nature of learning mathematically is said to benefit the growth or development of learners' creative thinking. In this respect engaging in problem-solving as illustrated in this chapter, may be regarded as a means of advancing creative thinking (Maharani, Siswono & Rahaju 2018) because problem posing demands from a student to rely heavily on (prior) mathematical content knowledge obtained through linking a variety of interrelated and pertinent mathematical concepts. This was exemplified in how both students with the aid of visual diagrams used the concept of second derivative and first derivative to determine the values of key variables that characterise the cubic function.

Integrating creativity with critical thinking enables individuals to tackle mathematical problems in ways that may challenge conventional approaches, as creativity fosters novel perspectives and the discovery of unexpected solutions (Matei 2023). This approach empowers students to cultivate essential 21st-century competencies, particularly in problem-solving strategies such as working backwards to address calculus problems — an increasingly valuable skill in today's rapidly evolving and disruptive society (Helaluddin et al. 2023). In addition to using information to arrive at precise solutions, these students illustrated through graphs how they mapped one piece of information to the next to build a solution that makes sense. Therefore, in order to improve students' thorough understanding of the subject, mathematics teachers are urged to employ cutting-edge strategies that stimulate critical, creative and self-directed learning in their students (Peter 2012). In a nutshell, both students in this task were able to successfully apply the working backwards method and analyse the known information with the assistance of sketch images or diagrams to solve for the unknowns in creative and novel ways. This meets the requirements of Posamentier and Krulik's (2009) backwards working strategy indicators, which are:

1. approaching problem-solving from the final result
2. reversing the process to find the original statement.

Conclusion

The working backwards strategy may be advantageous when there is a distinct endpoint (that which is to be proven and/or calculated) and a variety of components to reach the starting point. Backwards chaining through sub-steps coupled with working in the forward direction at times can enable students to see the solution to a problem. We do not want to imply that the workingbackwards approach should be used for every problem. As an alternative, one may attempt working backwards from the problem's natural (often forward) direction to see whether it yields a more interesting, efficient or satisfactory solution. Furthermore, we observed that almost all school textbooks and National Senior Certificate examination papers, ask learners to calculate the point of inflection of a given cubic graph first, and then ask them to discuss the concavity of the cubic graph, whereas it should be the other way around. We think the reasoning backwards with the aid of visual diagrams as well as the fact that many curriculum writers, textbook writers, examiners and teachers do not necessarily know that point of inflection should be concluded to exist only after concavity has been examined (Engelbrecht & Harding 2005; Vinner 1997) could provide useful opportunities for continuous professional development of our teachers and other related stakeholders.

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Chapter 13

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This scholarly book seeks to advance the discourse on innovative approaches to address the numerous challenges confronting science education in South Africa. Moving beyond the conventional focus on STEM, the book adopts a broader, interdisciplinary lens on science, technology, engineering, the arts, mathematics, and entrepreneurship (STEAME) education. Through a series of thoughtfully curated chapters, it delves into the pressing issues and emerging opportunities in STEAME education within the complexities of 21st-century society – an era increasingly shaped by artificial intelligence.

The unifying theme of the book centres on the pivotal role of engaging pedagogies in fostering self-directed learning – an essential foundation for South Africa's sustained progress in science and technology. With contributions from leading scholars, this volume is intended for academics, researchers, and science education educators interested in innovative teaching methods that can help under-resourced and disadvantaged students succeed.

While diverse in methodology, with contributions ranging from textual analyses to literature reviews and conceptual papers, each chapter aligns with the book's central goal of exploring forward-thinking solutions for STEAME education. A valuable resource for those seeking to shape the future of science education in a rapidly changing world, this edited collection, Volume 1 in the University of the Western Cape Faculty of Education Book Series, offers both theoretical insights and practical strategies.

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